Union, B.C. - Rice and rice as staple of merchant. (1918)

ECONOMIC SERIES No. 8

BRITISH MUSEUM (NATURAL HISTORY)

RATS AND MICE

AS

ENEMIES OF MANKIND

BY

M. A. C. HINTON

WITH 2 PLATES AND 6 TEXT-FIGURES

LONDON
PRINTED BY ORDER OF THE TRUSTEES
OF THE BRITISH MUSEUM
1918
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PREFACE

THE issue of a pamphlet dealing with Rats and Mice, and their depredations, needs no defence, and it may indeed be claimed to have a very direct bearing on the successful conduct of the war. Although the extent of the damage done to essential food-supplies by these small mammals is appreciated by all those who have had practical experience on a large scale, it is not sufficiently recognized by the majority of the community how great it is. The account given by Mr. M. A. C. Hinton in these pages shows how urgent is the necessity for co-ordinated action in reducing the numbers of Rats and Mice, which may fitly be described as the Enemies of Mankind, by reason of the enormous toll they take of his food, and of their agency in the dispersal of some of the most serious diseases which affect the human race.

Plates 1 and 2 and Text-figure 1 have been reproduced from original drawings by Mr. P. Highley, and fig. 2 from drawings by the author, Mr. Hinton. Figs. 3–6 are taken from Mr. G. S. Miller's "Catalogue of the Mammals of Western Europe," published by the Trustees in 1912.

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INTRODUCTION

Rats and mice, with some of their near relations, constitute a great zoological family, the *Muridae*,* which belongs to the order Rodentia. This order comprises the mammals characterised by a propensity for gnawing, a function performed by a pair of ever-growing chisel-like teeth, or incisors, placed in the forepart of each jaw. The distinction between a rat and a mouse is mainly one of size; larger species, such as those with a hind-foot measuring more than 30 mm.† in length, are "rats"; smaller species, with hind-feet less than 30 mm. long, are "mice."

Besides some native wild *Muridae*, Great Britain possesses three species which have been introduced, at different dates, from abroad; these aliens are the Black Rat (*Rattus rattus*), the Common Rat (*R. norvegicus*), and the House Mouse (*Mus musculus*). Possibly these three species are the most highly organised members of their family; but unquestionably they are the most successful of mammals. They are clearly of Asiatic origin; but uninvited, and unfortunately for us, they have linked their fortunes with those of humanity. Human enterprise, in all its phases, and human negligence have disturbed the balance of Nature in favour of these species, have afforded them an unnatural degree of protection from their many enemies, a large and

* In a strict zoological sense the names "rat" and "mouse" are only applied to members of the *Murinae*—one of the many sub-families into which the *Muridae* are divided. The three species which are the subjects of this work belong, of course, to the *Murinae*.

For the convenience of those who may wish to acquire a slightly more extensive knowledge of the *Muridae*, and would like to be able to distinguish the species inhabiting Britain, the writer has prepared a short account of the structure, classification, history and distribution of the principal divisions of the family. This, together with a "key" to the characters of the British forms, appears as an appendix (pp. 48).

† 25 millimetres = 1 inch.

unmerited share of the world's foodstuffs, together with perfect travelling facilities. Small wonder then that these creatures have invaded and colonised all lands, including those, like North and South America, which possess no native true rats or mice; that they have developed into serious pests, taking a heavy toll from human prosperity, and forming a most deadly menace to the public health.

The objects of this pamphlet are to give a brief account of these noxious animals, their habits and breeding; to deal with their economic importance and relations to the public health; and to suggest measures by which they can be controlled, if not exterminated.

I would take this opportunity of thanking Dr. S. F. Harmer, F.R.S., and Mr. W. P. Pycraft for much assistance and advice.

RATS AND MICE
AS
ENEMIES OF MANKIND

PLATES 1 and 2 and text-figure 1 (p. 37), will afford a better idea of the general outward appearance of the species in question than would be obtained by reading any detailed description.

1. RATS. Genus RATTUS.

The two species of rat met with in Britain may be distinguished as follows:—

1. **Rattus rattus.** The BLACK RAT, HOUSE RAT, or SHIP RAT (Plate 1).

Size smaller; general build elegant and slender; muzzle sharp.

Ears large, almost naked and translucent, reaching or covering the eyes when pressed forwards.

Tail slender, at least as long as, and often considerably longer than, the combined length of the head and body.

Pads of soles of feet relatively large.

Fur soft, but usually intermixed in adults with many slender grooved bristles, which impart a somewhat harsh quality and bristling appearance to the coat as a whole.

Teats: the females normally have ten mammae, two pairs on the chest, three pairs towards the groin; in some races an additional pair, making twelve in all, is present upon the chest.

Weight of adults rarely more than 8 ounces, usually less.

Measurements of two adults, in millimetres:—

Head and Body.	Tail.	Hind-foot, without claws.	Ear, from base.
188	224	38·6	26
214	252	38	25·5

2. **Rattus norvegicus** ("**decumanus**"). The Common Rat or Brown Rat (Plate 2).

Size larger; general build heavy and rather clumsy; muzzle blunt.

Ears small, densely clad with fine and short hairs, thick and opaque in substance, scarcely reaching the eyes when pressed forwards.

Tail stout, never as long as the combined length of the head and body.

Pads of soles of feet relatively small.

Fur softer than in *R. rattus*, the grooved bristles more slender and in smaller number.

Teats: the females normally with twelve mammae, three pairs on the chest, three pairs towards the groin.

Weight of adults normally from 14 to 17 ounces; but specimens weighing between 20 and 30 ounces have been frequently recorded; one mentioned in the *Field* (Sept. 20, 1913, p. 666) is said to have weighed 2 lbs. 12 ozs.

Measurements of two adults, in millimetres :—

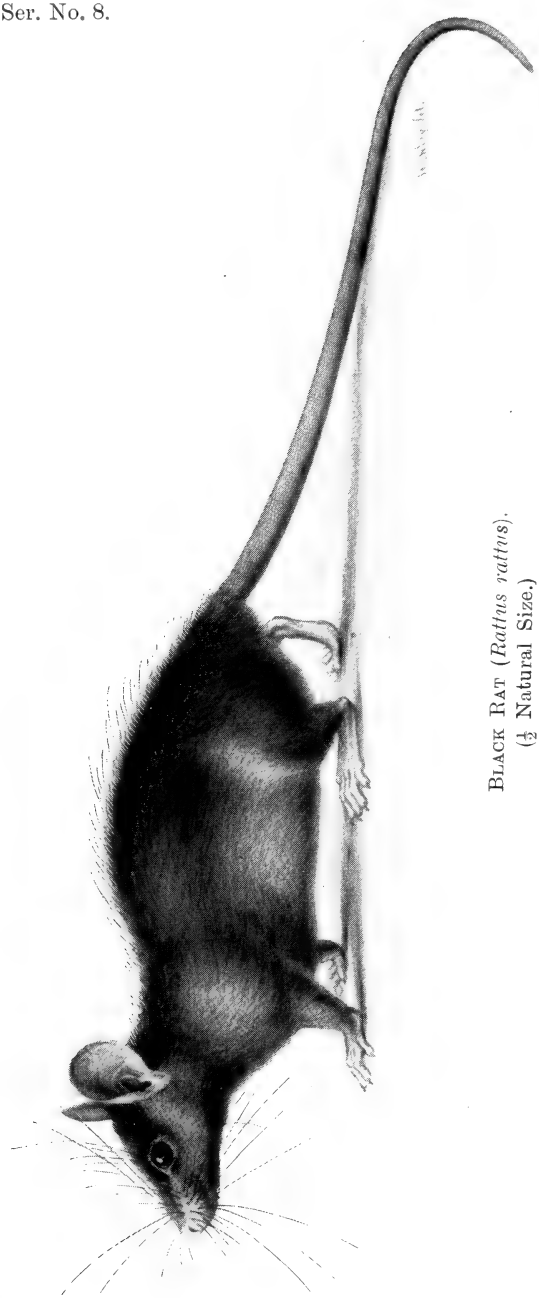
Head and Body.	Tail.	Hind-foot, without claws.	Ear, from base.
254	222	43	20
267	229	45	20

Good characters for the distinction of the two species are also afforded by their skulls, which are described and figured on p. 59.

It will be observed that nothing is said about colour in the above comparison. The reason for this deliberate omission is the fact that the specific determination of any given rat in Britain must depend upon the characters mentioned above, and not upon its colour. Inattention to this point has led many observers into error; because most "Black Rats" are brown, and many "Brown Rats" are black. Colour only becomes important after we have determined the species, when it is used to distinguish between the sub-species or races.

SUB-SPECIES AND HISTORY OF THE BLACK RAT, *R. RATTUS*.

Three well-marked colour and pelage phases of this species occur in Europe; all three may be found living together in the same colony, or may occur occasionally in the same litter in



Black Rat (*Rattus rattus*).
(½ Natural Size.)

[*To face p.* 2.]

Brown Rat (*Rattus norvegicus*).
($\frac{1}{2}$ Natural Size.)

[*To face p.* 2.]

colonies of mixed origin; nevertheless, since each has a certain geographical value of its own, and since each may breed true to its type, it is not only convenient but natural to regard each as a distinct sub-species. These sub-species may be defined as follows:—

1. *Rattus rattus rattus.* The Black Rat.

Back black; belly smoky grey. Fur on back long and rather harsh; on belly short, sleek, and adpressed. (This, technically the type of the species, is essentially characteristic of the cold temperate countries of Europe.)

2. *Rattus rattus alexandrinus.* The Alexandrine Rat.

Back brownish grey; belly more or less dingy; dorsal and ventral colours merging insensibly in each other on flanks. Fur usually rather harsh on back; on belly usually longer and rougher than in *R. r. rattus*. (Essentially characteristic of Asia Minor and North Africa.)

3. *Rattus rattus frugivorus* ("*tectorum*"). The Roof Rat or Tree Rat.

Back yellowish or reddish brown; belly pure white or pale lemon; dorsal and ventral tints separated on flanks by a sharp line of demarcation. Fur very soft and full, with few bristles; particularly long and dense on belly. (Essentially a wild-living rat, inhabiting Sicily, Italy, Spain, and the Mediterranean region generally.)

All these forms have been conveyed by human commerce to the various ports of the world. Where they have not had to compete with native races of *R. rattus*, or with the more formidable *R. norvegicus*, and have met with suitable climatic conditions, they have frequently established a strong foothold and have colonised large tracts of the interior.

All forms of *R. rattus*, whatever may be their colour, seem to have descended from a bright coloured, soft furred stock, closely resembling *R. r. frugivorus*. Such rats, differentiated into many local sub-species, abound in India and Burma, and there can be little doubt that these countries were the cradle of the species; there, as in the Mediterranean islands, the white-bellied races are frequently found living a wild, more or less arboreal, life in the open country, far away from all human habitations.

The species does not appear to have been known to the ancient Greeks or Romans, and although a Roman altar (dating from 100–150 A.D.) in Rheims Cathedral is stated to bear the figure of a rat, there is no clear evidence of the presence of the species in western Europe before the time of the Crusades. No doubt the navies of the Crusaders were largely instrumental in bringing this animal to our shores. Where climatic conditions permitted, as in Sicily and the Balearic Islands, the species resumed a natural life in the open, and it has maintained its primitive wild coloration.

In cooler countries, or in those with a greater range of temperature, the species was forced to spend a good deal of time within doors; in such circumstances it has developed a darker belly and harsher fur, producing by such means the race called *R. r. alexandrinus*. A parallel change may be studied among some of the Indian races, notably among those of the Central Provinces and Kathiawar.

In colder countries, like Britain or Germany, the species was only able to survive with the aid of the shelter provided by man. In such regions it has entirely lost its primitive bright coloration and has assumed the dusky garb of *R. r. rattus*. This last change appears to have been brought about rapidly; for although the rats imported by the Crusaders cannot have been any darker than is *R. r. alexandrinus*, their descendants by 1530 at the latest, judging from the descriptions given by Georgius Agricola and by Gesner, had acquired the full black dress.

Once firmly established in the dwellings and stores of Western Europe, *R. rattus* multiplied to an amazing degree; it became and remained throughout the Middle Ages, to the beginning of the eighteenth century, a frightful pest, destroying much property and food; moreover, the terrible outbreaks of plague, by which the populations of Europe were so frequently devastated, are undoubtedly to be ascribed to this animal and its parasites.

The arrival in temperate Europe of the Brown Rat, *R. norvegicus*, from the East, in the early eighteenth century, introduced a new factor; a much stronger, more formidable and fecund animal, by nature used to and fitted for a hard life in a cool country, this rapidly spread over Britain; wherever it came in actual contact with *R. rattus* it killed the latter out, and it speedily, within the space of fifty years, reduced the range of the weaker species to a series of isolated and ever dwindling colonies. In this country,

save for the waterside colonies,* continually replenished or re-established by ship rats, *R. rattus* appears to have become extinct shortly after the middle of the nineteenth century. No doubt the rebuilding of much riparian property, and the gradual substitution of brick and stone buildings for houses of wood, lath, and plaster, throughout the country, have contributed largely to the extermination of *R. rattus* and to the hindering of its incessant efforts to re-colonize our land.

In warm countries it has less to fear from the competition of the Brown Rat, and in many, as in India, it remains the dominant species. At sea its superior climbing powers give it a great advantage over the Brown Rat; it therefore continues to be the principal ship rat. The races *frugivorus* and *alexandrinus* form a large percentage of the ocean-going rat population.

COLORATION AND HISTORY OF THE BROWN RAT, *RATTUS NORVEGICUS.*

The normal colour of *R. norvegicus* may be described as follows:—Back greyish, or reddish-brown, heavily "lined" with black hairs along the spine; belly silvery grey, but in many specimens washed with a dingy yellowish-brown.

It is of especial interest to note that this species, although first established in Britain within the last two hundred years, is already developing a **Black** race—described originally from Ireland in 1837 as "*Mus hibernicus*." This black race (frequently confused with *R. r. rattus*) is becoming commoner and is acquiring a wide distribution. Should it ever become the prevalent form of the species in this country, it would then afford a complete parallel with *R. r. rattus*, the evolution of which has been described above.

The tame rats of commerce are apparently all of this species;

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* One of the best known colonies of *R. rattus* living in Britain is that discovered at Yarmouth in 1895 by Mr. A. H. Patterson, who has published several accounts of it from time to time. Between 1905 and 1910 these rats increased greatly in numbers and made steady progress through parts of Yarmouth. With reference to this colony, Mr. Patterson, *in litt.* (April 1918) to Dr. Harmer, states that the species "which is much harassed now is becoming rarer. . . . The war allows no grain ships here, so that the species does not now breed ahead of its destruction. I, however, get three or four dead ones a week."

by ordinary selection and by Mendelian breeding experiments a very large number of colour and pattern variations have been produced.

The home of *R. norvegicus* is in temperate Asia; according to Kastchenko the typical form inhabits the territory between the shores of the Caspian Sea and Tobolsk, while another wild form, *R. n. primarius*, is found in the region to the west of Lake Baikal. No wild representative of the species is met with in any other part of the continent; this discontinuous distribution points to the long standing of the species in Asia.

The ancients may have heard something of the Brown Rat; at any rate, Ælian's description of the habits of his "*Mures Caspii*" fits this animal quite well. The people of Western Europe, however, had no knowledge of the species until 1716, when it was introduced to Copenhagen as the result of a visit by the Russian fleet (*Winge*). In the year 1727, a "mouse year" in the Caspian region, vast hordes of these rats, according to Pallas, moved westwards after an earthquake (but probably in search of food); they swam across the Volga and swarmed into the houses of Astrakan. Thence they spread across Russia into Western Europe.

The species came to England, probably by ships trading with Russia, in 1728 or 1729; but it is not known to have occurred in Scotland before 1764. It is said to have reached Paris and East Prussia in 1750; Norway in 1762 (common there in 1776); the Faeröes in 1768; Sweden in 1790; Spain about 1800; and Switzerland in 1809. It was introduced to the United States about 1775, and is now common in most of the thickly populated parts of America; it is also found in many of the remote districts of both North and South America. In short, it has now spread with commerce to all countries. It meets with its chief success as a colonist in those of a temperate character; in very cold lands it is entirely dependent upon the shelter given it by man; and in warm regions it is frequently unable to displace *R. rattus* and its allies.

GENERAL HABITS OF RATS.

The wide differences in the structure of the two species discussed in this pamphlet are naturally correlated with some considerable differences in their habits. Certain habits are, however, common to both. Thus, both are, in the main, nocturnal or crepuscular, and they spend much of the day sleeping in warm

nests of grass, rags, paper, or other soft materials, placed in their holes or burrows. Into these retreats they habitually carry much food, so that when circumstances do not permit of foraging expeditions (*e.g.*, during bad weather out of doors, or when danger threatens within) they are able to remain concealed and secure for a considerable time. They seek to establish their nests as near to their food-supply as possible, but often undertake quite considerable journeys to other feeding places. If the latter are far from home, temporary hiding-places are usually established; and if the new food-supply be attractive, such temporary refuges may be converted into permanent dwellings and the old nest abandoned. On their journeys they follow definite paths or runs, from which they rarely deviate voluntarily. In the open, these runs are readily found, and may be distinguished from those of rabbits by the continuously smoothened surface and the spindle-shaped droppings. In buildings, the runs are no less definite, and they may be found by sprinkling the floor with powdered materials. In rooms, they usually keep close to the walls, sometimes on the floor and sometimes along skirtings or pipes. Rats are extremely wary, and highly suspicious of traps; but they may be frequently caught by unbaited traps, if the latter be properly set in their runs. While grain may be considered their staple food, they greedily devour everything edible that comes in their way, be it animal or vegetable. Like all other rodents, rats have to gnaw hard substances regularly in order to keep their ever-growing incisors at a proper length; in default of wood for this purpose rats will attack all sorts of materials—leather, bone, ivory, lead pipes and sash-weights, brick, and even cement being among such substitutes.

R. rattus is essentially an arboreal or climbing animal, and it rarely burrows; hence, where infesting buildings or huts, it is found usually in the walls, ceilings, or roof, not in cellars or drains. Although cautious, it does not shun mankind, and it enters into far closer relations with its unwilling host than does the Brown Rat. For this reason it is often the species principally concerned in the transmission of plague. It drinks little, and seldom, if at all, enters water voluntarily. As already mentioned, this is the common rat on ships. In most cases it reaches or leaves the ships by climbing their cables while they are in dock; sometimes it is introduced with grain and other merchandise. Its diet is of a most varied description, but, probably in consequence

of its more salubrious station, it is a far cleaner feeder than *R. norvegicus*.

R. norvegicus is essentially a water loving and burrowing animal; although far less agile than *R. rattus*, it is also a good climber. As compared with the last named species, it is far more voracious and cunning; its greater size and strength, and its much greater fecundity, render it, so far as material prosperity is concerned, a much more formidable enemy of mankind. On the other hand, although it spreads many serious or fatal diseases, it usually exhibits a certain shyness of man, so that, in normal conditions, it is probably slightly less important than *R. rattus* as a carrier of plague.

It possesses a remarkable power of adapting itself to the most varied surroundings. Thus, although extremes of heat and cold are unfavourable to its development and continued success, it may be found living in many hot countries and also in cold storage stations. At Tammerfors, a little town of wooden buildings in western Finland, and a very cold place, it has, according to Zuschlag, invaded the houses and completely replaced the House Mouse. Here it has become most impudent and bold; it is to be found even in the beds of the inhabitants. In such conditions it must constitute a grave menace to the public health. Again, in South Georgia it is regularly found out of doors in the summer, living amongst the coarse tussock grass of that wind- and snow-swept island, and preying upon the eggs and young of the sea-birds.

The only factor indispensable for the success of this species is the presence of water; it drinks freely and displays great skill as a swimmer and diver. Naturally, therefore, it abounds along the banks of all watercourses; and these play a great part in directing and facilitating its advance in a new country, as well as its seasonal movements or "migrations." It infests sewers and drains, not only for the sake of the water flowing through them, but because ordure serves it quite well as food. From such haunts it readily passes into the basements of buildings, and in those houses which have their tanks in the roofs it often finds its way aloft. Where a rat has found such a pleasant and safe drinking and bathing place it will sometimes visit it with the utmost regularity for a considerable period; if living out of doors, the rat will enter such a house, and leave it again after bathing, night after night, by a regular run, which may include a long climb through a stack pipe and a tortuous passage through walls,

partitions and ceilings. Again, attracted by the food of the pit ponies, as well as by the drainage, rats find coal mines quite comfortable places to live in; and they often find their way from one mine to another.

Whenever necessary this species digs with great facility. Out-of-doors its burrows consist normally of winding galleries, drilled in banks or hedgerows, and furnished with several bolt-holes. The burrows are frequently established in soft and warm materials, such as manure heaps and rubbish mounds; wheat stacks, hay ricks, and thatch also offer special attractions and are often riddled with rat holes. It shows a good deal of inquisitiveness, and will dig out bulbs and roots from garden beds, sometimes, apparently, merely to satisfy its curiosity. Furthermore, every passing rat will be attracted by the spoor of its predecessor, so that if one marauder be caught another soon takes its place.

This species carries out a partial migration at different seasons. In spring many individuals from farm buildings and towns betake themselves to the open fields, where they establish burrows and pass the summer. As autumn advances many forsake the fields and re-enter buildings for the winter. It is said that in years with a plentiful acorn crop fewer return to houses and more remain to pass the winter in the open. The breeding rate, however, depends upon the amount of food available and upon the competition for it; the rat population in the buildings is quickly compensated for the extra number left behind in the fields, and in the following spring the numbers migrating for the open are not sensibly diminished. During the ensuing summer the outdoor rat population rises much above the normal. Similar movements are connected with periodical changes in food-supply; thus, it is said that large numbers of rats visit our coast during the herring fishery, and that they pass inland again in October after this fishery has stopped. In all these movements waterways of all kinds, as already mentioned, play a large part. Mr. R. E. Parker of Norwich, *in litt.* to Dr. Harmer, says: "Lynn . . . is infested with rats which annually migrate over W. Norfolk—they are destroyed in hundreds at Sandringham. We find always that rats in a dry time in spring return to the rivers and in autumn they come back up the rivers. You may have a farm clear of rats one week and well stocked the next."

Although rats attack and devour such of their fellows as are injured and too weak to defend themselves, they are normally

friendly and sociably disposed towards each other. New-comers are received as comrades, and if more than three be present in a cage or sack a man may put his hand in among them and handle them with impunity. In some circumstances, as when impelled by hunger, they are extremely bold and will attack man and other large mammals; they have thus been known to attack and kill a man who descended into a mine which had been shut down for ten days, to attack sleeping persons, to gnaw the toes off lepers too weak to resist, and to mutilate corpses in a mortuary; attacks upon the feet of living elephants, and upon the ears, backs, and teats of live pigs are also recorded. Some years ago a large number of rat-infested houses were demolished in London. As soon as the buildings were deserted and the food supplies ceased, the rats swarmed into a neighbouring restaurant; here their competition for food became so keen that they would sometimes jump upon the luncheon tables, seize and bolt away with morsels of food from the plates of the customers. In another restaurant hard by, the writer once saw three rats emerge from a chimney one after another and jump on to the floor across a large and fiercely glowing fire; but this was towards the end of the day when all was quiet.

Rats hunt small vertebrates with great zeal, and sometimes show such ferocity as to suggest a lust for killing. Young rabbits in warrens, and the eggs and young of game birds, fowls, and ducks are frequently devoured. The rat frequently shows the greatest cleverness in stealing eggs, taking them from under a sitting hen without disturbing her, or from packing cases without breaking them, and removing them often over a considerable distance and many obstacles to the burrow. Rats soon find their way to the places where domestic animals are fed, and become regular visitors; thus, they used to swim across the Regent's Canal every evening to steal a share of the provisions supplied to the inmates of the Zoological Gardens.

BREEDING HABITS OF RATS.

Rats and mice are, as is well known, very prolific. They attain sexual maturity long before they have completed their growth. Thus, the Plague Commission found the minimum weight for sexually mature individuals to be at least 70 grammes (about $2\frac{1}{2}$ oz.) in *R. rattus* (at Bombay), and at least 100 grammes (about

3½ oz.) in *R. norvegicus*; but the average weight of apparently adult specimens is certainly not less than 140 grammes (about 5 oz.) in *R. rattus*, and 250 grammes (about 9 oz.) in *R. norvegicus*. "Apparently adult rats" are those in which the coat and colour are similar to those of old animals, in which the hind-foot measurement amounts to less than 25 per cent. of the head and body length, and in which, being females, the vagina is perforate; such rats are certainly at least four months old; growth continues until they are eighteen months old, and perhaps does not cease then. De l'Isle, experimenting with *R. rattus*, found it to be sexually mature when less than three months old; and F. Buckland records that a female *R. norvegicus* in captivity bore a litter of eleven young when only eight weeks old, so that she must have been impregnated at the age of five weeks.

Although rats breed in every month of the year, pregnant and nursing females are more common between the months of January and June than at other times. Full-grown males, in good health and normal conditions, appear to be capable of pairing at all times. The females can only pair at certain times; they have a long sexual season, extending (for any particular female) possibly through nine months of the year. During this season they experience desire, or come on "heat," in the absence of the male, at intervals of about ten days, but "heat" lasts for a few hours only; if not satisfied it subsides, and the female cannot then be impregnated until her next "heat." The period of gestation is normally about twenty-one days; but if the female be already nursing at the time of impregnation, the development of the embryos may be retarded, and the period is prolonged by another ten days or so. During the sexual season some evidence of the regular recurrence of "heat" is shown even by the pregnant female; and parturition, in the season, is immediately followed by "heat," so that impregnation is renewed within a few hours of the birth of a litter.

Lataste, to whom primarily we owe a very large share of our knowledge of the breeding habits of *Muridae*, found that after effective coitus the vagina is plugged by a stopper, the purpose of which apparently is to prevent the escape of semen from the female before impregnation has taken place. This vaginal stopper is a joint production of the sexes, its larger, central and quickly coagulating portion being furnished by the male. The stopper remains in place for some hours, and is then expelled from the vagina.

It may be mentioned here as a point of practical importance

that, as in other *Muridae*, the urethra of the female passes through the prominent clitoris; in mature does, the vagina is a conspicuous orifice between the clitoris and the anus; but in immature females the vagina is sealed and quite invisible externally, and such specimens can frequently be mistaken for males; distinction by mere inspection is, however, possible, because the distance between the clitoris and the anus is less than between the penis and the anus.

The number of litters per doe per annum and the number of young per litter are dependent upon many factors, of which the most important are food supply, the age and condition of the female pairing, and, in a much lesser degree, climate and temperature. *R. rattus* probably shows a higher fecundity in warm temperate countries than in cold temperate lands; *R. norvegicus*, on the other hand, is more fecund in cold temperate climates. Increased nutrition not only leads to larger and more frequent litters, but it almost certainly results in decreasing the mortality among very young rats. Although very good and careful mothers, as a rule, female rats eat their offspring in certain conditions, such as when overcrowding leads to disturbance or to too keen competition for supplies. In Newton Miller's experiments with *R. norvegicus* in captivity 50 per cent. of the young born were thus devoured.

The embryos of the pregnant females among 12,000 rats trapped at Bombay were counted, with the following results:—

	R. rattus.	*R. norvegicus.*
Average number of young per litter	5·2	8·1
Maximum number of young per litter	9	14

In Europe *R. rattus* is described as bearing from four to eleven young in a litter; probably the normal number per litter in Britain is between six and eight.

As regards *R. norvegicus*, twenty-three litters examined by Mr. A. H. Cocks, at Great Marlow and Poynetts, Bucks, gave a range of from six to twelve per litter, the average number being nearly eight per litter. This may perhaps be taken as a measure of fecundity in rural conditions.* But much larger litters are frequently observed, particularly in towns. Litters of seventeen, nineteen, twenty-two,

* Between January 16 and February 14, 1911, Petrie and Macalister examined 6,071 specimens of *R. norvegicus* collected in Suffolk and Essex during the period specified; of these 3,273 were males, 2,724 females, and of 74 the sex was not recorded; 290 or 10·6 per cent. of the females were pregnant, the average number of fœtuses being 9 (**7**, p. 60).

and twenty-three have been recorded; and Lantz thought it safe to conclude that the average is not less than ten per litter. Newton Miller's experiments gave an average of between ten and eleven, the number per litter ranging between six and nineteen; his evidence also showed that the females produce five or six litters annually.

The young are born in a helpless condition, being blind, naked and pink, with their external ears sealed down. Their eyes open at about the fourteenth day, and they are weaned in the course of their fourth week.

THE ECONOMIC IMPORTANCE OF RATS.

We have now to consider rats from an economic standpoint. In such discussions we usually find two sides to the account—credit and debit. Unfortunately there is practically nothing that can be placed to the credit of either *R. rattus* or *R. norvegicus*. Their activities as scavengers are no longer of the slightest benefit to humanity; the most that can be said for either perhaps is that they may keep the numbers of House Mice to some extent in check. On the other hand, the debit account is long and deplorable.

Damage occasioned by rats.—That rats do great damage to property and materials of all kinds is a fact only too well known to the public. Therefore, there is no need to review in detail all the misdeeds of these animals; we may be content with mentioning some of the chief heads of damage.

Property.—By burrowing under foundations, through walls and embankments, and by gnawing their way through partitions, doors, and joists rats cause great damage to property. Such operations have sometimes led to serious structural collapses and considerable monetary loss. By gnawing through gas and water pipes they occasion great inconvenience and sometimes serious danger; by carrying matches into their combustible nests and igniting them, and by gnawing away the insulation from electric lighting wires, they have caused destructive outbreaks of fire and sometimes the death of the human residents.

Materials and Food.—In docks, warehouses and shops, and while in transit by rail or sea, large quantities of merchandise, of the most varied description, are annually destroyed or more or less seriously damaged by rats. In houses, hospitals, and other institutions they display a most catholic taste—food, furniture,

books, linen, pets, and sometimes man (alive and dead) being attacked.

To agriculture in all its branches the Brown Rat is especially a most dangerous pest. Grain of all sorts is undoubtedly the chief and favourite food of the rat. Before the grain is sown, in every stage of its growth, and after the harvest, wherever it is stored or in whatever form it is used, it is subject to attack by this animal. An enormous toll is thus levied upon farmers, millers, grain merchants, and consumers—a toll which is difficult to appraise, but which, in the case of the farmer, must often be equal to rent and taxes combined. People who keep animals for profit or for pleasure sometimes feed, regularly if unwittingly, some hundreds of rats in addition to their stock. Poultry farmers, breeders of game-birds, pigeon fanciers and others suffer great losses in this way; what is worse, their eggs are regularly stolen, their young and even their old birds are attacked and killed. Pigs and other large animals are often destroyed, or rendered worthless, either by reason of deliberate attacks upon them made by rats, or through coming in contact with or devouring rats or food contaminated by the latter. In warrens, large numbers of young rabbits are destroyed. Great havoc is sometimes wrought among root-crops, and all kinds of fruit and vegetables are greedily devoured.

In short, every description of food for man or beast, whether in course of production, store, or use, is subject to the attacks of the rat. The quantity actually eaten or carried away is very considerable, but far more is ruined than devoured; and when food, rat-tainted though still wholesome in appearance, is used it sometimes entails disastrous consequences to the health of man or that of his domestic animals.

Such damage is not confined to Britain; it is caused throughout the world wherever the Brown Rat has gained a footing. In favourable circumstances rats multiply with amazing rapidity, and they speedily bring utter ruin and devastation in their train. Two small instances of this may be quoted. Deget is a small island in the Cattegat. According to Zuschlag, the rat was quite unknown there until two boys introduced a pair of tame rats, which they had purchased in Jutland. These pets escaped. In less than two years their progeny became a plague infesting the whole island and succeeded in exterminating the numerous birds, which until the establishment of the rats in such numbers used to breed there.

The second case is that of Lesser Cumbrae, an island of 900 acres in the Firth of Clyde. According to Boelter (quoting from *Chambers' Journal*) rats had been known on the island for a number of years, but they seem to have given no particular trouble. Then a French ship was wrecked and its rats made their way to the shore; they multiplied at a tremendous rate, and in the course of four years developed into a serious plague. In 1907 the keeper lost five tons of turnips; at Christmas the rats attacked, killed and devoured a 20lb. turkey. The rabbits, rose bushes, wild duck, mangolds and woodcock inhabiting the island were threatened with extermination. At last virus was used (this time with success, be it noted) and the rats succumbed.

Various estimates of the value of the damage caused by rats to property and materials in Britain and other countries have been published. Quite apart from the difficulty or impossibility of obtaining accurate information as to the number of rats inhabiting any given country, it is most difficult to estimate the loss. On the one hand, although rats consume and spoil vast quantities of food and materials, both in course of production and in store, they also eat much matter which is purely waste. And further, while in some cases the damage done is promptly detected and recognized as being due to rats, and the loss occasioned has a definite measure, in the majority the damage is done unobtrusively and silently to things which are developing and of which the value has not been ascertained. The loss is often gradual and not easily detected (as when food is stolen from the supplies of domestic animals); but it is continuous and soon totals up to a large sum.

To the actual damage caused by rats we have to add the large sums which are annually expended by public bodies, companies, and private individuals on rat-catching operations. According to Boelter, the capital employed in this country in providing rat-catching or rat-killing apparatus had grown to £2,000,000 in 1909.

Boelter assumed the rat population of Great Britain to be 40,000,000—*i.e.*, about one to each acre cultivated, or one per head of the human population. He further assumed that each rat on an average occasioned a daily loss of one farthing; on these assumptions, the total annual damage done by rats in this country amounts to £15,000,000. This estimate does not take into account the damage done by rats on our ships; it relates solely to the rural and urban activities of these animals. The estimate received the approval of Sir J. Crichton-Browne, and enquiries made of a very

arge number of the people who throughout the country are brought most closely in contact with the rats, elicited the fact that none thought either of Boelter's premises excessive, while many thought them too low. Dr. Shipley, on the basis of a similar assumption as to the size of the rat population, estimated the annual damage in Britain at £10,000,000.

On a later page (p. 60) a table dealing with the rat population of Britain and its expected increase in the current year is given. On the basis of that table we have endeavoured to estimate the minimum loss which will be inflicted upon us this year by rats. In these calculations we have assumed an excessive mortality and waste among the rats; we allow nothing at all for the maintenance of rats not yet capable of breeding; and we suppose that they will not breed until they are four months old. The cost of maintaining the breeding stock is assumed to be no more than one farthing a day for each rat, but the sum works out to a total of £9,224,000.

In other countries the annual loss attributable to rats has been estimated similarly to reach huge totals. In Denmark it is said to amount to 15,000,000 francs; in France the loss occasioned in 1904 was estimated at 200,000,000 francs; the loss in Germany is officially estimated at 200,000,000 marks; and in America the Biological Survey estimates that the direct annual loss sustained by residents in the towns and cities of the United States amounts to 20,000,000 dollars, while the total annual damage inflicted throughout the United States is put at 200,000,000 dollars.

RATS IN RELATION TO DISEASE.

However estimated, the financial loss occasioned by rats, in wasting our food, materials, and property, must appear colossal. But that loss sinks to insignificance when we consider how grave is the risk of disease entailed by the presence of these pests in our midst. The financial loss directly affects, perhaps, only a comparatively small number of people, and many of these, ignorant of its extent, are quite indifferent to its cause. The menace to health is real, and it affects every member of the community. In spite of the excellent and unremitting efforts of our Public Health and Port Sanitary Authorities, that menace will last and will grow steadily so long as there is a large and increasing rat population in this country. The list of diseases disseminated by the rat grows

as biological and medical studies proceed. In this place we can discuss only a few of them, but the few will suffice to prove that, even in these days, humanity possesses no more deadly enemy than the rat, and that the rat problem is as serious and urgent as any before the public at present. Whatever the cost in labour or money may be, the extermination of the rat is a necessary step for the public safety.

Plague.—The great tragedies wrought by this disease in Western Europe, from early mediæval times down to the beginning of the last century, are familiar to all. Plague is by no means extinct. During the last twenty years it has killed millions of people in various parts of Asia; from the East it has spread and is still spreading to all quarters of the globe. It shows everywhere a virulence of type which augurs ill for Europeans should they fail to keep the disease under control. In almost each of the last ten years several deaths have occurred in Great Britain.

Plague is a disease of the circulatory and respiratory systems resulting from an invasion of the body by a minute organism, the *Bacillus pestis*. The disease exists in two forms, viz., Bubonic plague and Pneumonic plague; these differ merely in their mode of infection and symptomatically. In bubonic plague the blood is infected; typically, the bacilli are arrested in the glands, which swell into buboes and suppurate. In more acute cases the glands fail to arrest the bacilli, and the battle between the latter and the phagocytes is fought out in the blood, giving rise to what is called "septicæmic plague." In pneumonic plague the pulmonary organs are infected with the bacilli, and the ensuing symptoms closely resemble those of pneumonia. In either form the disease, in the majority of cases, terminates fatally.

This dreadful scourge belongs essentially to rats and the peculiar species of fleas infesting them; it is Nature's unfailing method of periodically reducing the rat population to reasonable proportions. The rat fleas feed on the blood of an infected rat; at one meal a single flea can take with this blood as many as 5,000 plague germs into its stomach. *Bacillus pestis* multiplies in the stomach of the flea rapidly—so rapidly that an obstruction is often formed in the alimentary canal of the flea near the entrance to its stomach. Such a flea grows hungry, in due course, and endeavours to feed; but although it can still pump blood from its host, the obstruction in its gullet prevents it from swallowing, and so the blood is forced back into the wound; the

mouth of the flea becomes contaminated and infested with plague germs. In due course the plague-smitten rat dies, and its fleas have to seek other hosts. If another rat presents itself, the fleas collect on it. The "hungry fleas" at once attempt to feed; they bite and pump blood again and again, each time forcing contaminated blood back into the system of the new host. The latter is speedily infected with plague; and so the disease goes on spreading in an ever-widening circle, and a great mortality ensues among the rats.

Rat fleas carrying plague germs do not, unfortunately, always select another rat as the successor of their first host. They often collect on other rodents, and they have been known to infect horses, dogs, and pigs. But very often man himself is the new host, and a single germ is sufficient to infect him with plague. In man such an infection always takes the form of Bubonic Plague. This is not contagious; it can only be transmitted to man by a direct blood infection, as by the bite of rat fleas. At a later stage, however, plague becomes more virulent among humanity; it develops into Pneumonic Plague, which is highly contagious. Unless checked, it now becomes epidemic and spreads death on every hand among the unfortunate people attacked.

Often the advent of plague among people is heralded by a noticeable mortality among the rats; but this is not invariably the case, for men are sometimes attacked before the disease has made any visible strides among the rat population. Plague is quite frequently detected among the rats in British ports; it is constantly arriving in this country, and every year deaths from it occur among the human inhabitants. In East Suffolk, between the Orwell and the Stour, plague seems to be endemic among the common rats; several human deaths from pneumonic plague have occurred at various localities there in recent years. These cases have recurred after intervals of many months, and in spite of the most active and careful preventive measures known to sanitary science. They serve to show that plague, once firmly established, is most difficult to eradicate, and to warn us of the fact that we can afford to take no risks in this matter.

Trichinosis.—Rats and mice are the principal agents concerned in disseminating and perpetuating this disease. The cause of trichinosis is a very remarkable parasitic worm, *Trichina spiralis*. Large numbers (often millions) of immature *Trichina* are sometimes found embedded and encysted, in calcareous envelopes, in the

muscles of mammals and birds. Individuals so infested by the parasite are said to be trichinous; the common rat, the pig, and man share the unhappy distinction of being the species most frequently infested. While encysted the immature *Trichina* remain in a state of suspended animation, and are therefore incapable of further development. This inertia, which may last for many years, is only overcome if and when another warm-blooded vertebrate devours a portion of the trichinous flesh. In the course of digestion the gastric juices dissolve the calcareous cysts and the young *Trichina* emerge in the bowel of their new host. They now grow rapidly and perfect their sexual organs. The sexes are distinct, the males being smaller than the females. This development takes three or four days; within a week the *Trichina* are fully adult, and pairing takes place. The females carry enormous numbers of ova (1,000 to 15,000); after fertilization these develop and are hatched within the body of the mother, the young being eventually brought forth alive. Young *Trichina* begin to appear in the intestine at about the eighth day after infection; they at once migrate by perforating the walls of the alimentary canal and the abdominal cavity, and so find their way into the muscular tissue, where they encyst themselves. The migration takes about ten days, and the encystment commences in about fourteen days. Each young *Trichina*, as a rule, forms its own cyst; but sometimes cysts containing two, very rarely even three, of the worms are found.

Such is what may be termed the normal life-history of this parasite; but of the large numbers sometimes liberated in the bowel on infection, and of the enormous numbers born subsequently, a certain proportion usually escape from the alimentary canal of the new host with the fæces. An animal feeding upon such trichinous excrement will also be infected.

Man is infected by eating trichinous pork, particularly when raw or only partially cooked. In spite of microscopic examination of carcases, it is impossible in practice to guarantee that any given pig is absolutely free from encysted *Trichina*, and as a matter of precaution every particle of pork should be thoroughly cooked before being eaten. No less than 32 per cent. of the German cases, between 1881 and 1898, were traced to pork officially inspected and passed as being free from this parasite. Trichinosis in man is a very serious malady. Infection is followed by nausea, loss of appetite, diarrhœa, and fever; later, when the young

Trichina are born, and their migration commences, there is further fever, exhausting diarrhœa, and much pain and swelling in the muscles. The chance of surviving infection depends upon the vitality of the patient and the extent to which he is infected. If he survives the migration and encystment of the young *Trichina* he will be safe, since the parasites now become inert, but he may feel bad effects from their presence for many years. Mortality in cases of trichinosis is high; in one instance a single pig, converted into sausages, caused 337 cases of trichinosis, and of these 101 terminated fatally.

The pig is infected with *Trichina* by devouring the bodies of dead rats and mice, or food fouled by the excrement of these animals. The Common Rat is the chief host of the parasite; the latter is, however, not uncommon in the House Mouse. Rats and mice devour the bodies of their fallen comrades; they do not despise food contaminated with their droppings; and rats feed upon the dung of other animals. Further, in slaughter-houses, rats often have an opportunity of feeding upon the trimmings from trichinous flesh; in Glasgow City Abattoir 3 per cent. of the rats were found to be trichinous. In these various ways these rodents ensure the continued existence, abundance, and wide dissemination of *T. spiralis*.

Sokodu, or Rat-bite Fever, results from infection ensuing upon the bite of a rat. The wound is said to heal rapidly and apparently normally, but after an incubation period, varying from a few days to a month, it becomes inflamed and painful. This is followed by rapid variations in temperature, and symptoms of serious systemic infection; the kidneys in particular are badly affected. Death may occur from nephritis, or from exhaustion. If not immediately fatal, the disease assumes a relapsing form; its course may extend over several months. In one case it developed into a progressive wasting with recurrent fever lasting for eight years. (For further details and treatment *see* Longman, p. 26.)

Influenza in an acute form occurs among horses, and it is conveyed from stable to stable by rats. Where the outbreak of the disease has led to the closing of a stable, the disease usually appears promptly in the other stables of the neighbourhood, because the rats migrate from the closed stable so soon as their food supply stops. An even more striking illustration is afforded by the outbreaks of equine influenza among the ponies of adjoining coal mines.

Similarly, foot-and-mouth disease and dysentery are now known to be carried by rats.

Finally, the Common Rat makes its way into the store-places and kitchens of our houses and restaurants. Into these places, besides contaminating our food with its own germ-laden dejecta and parasites, it brings a wealth of indescribable filth from its favourite haunts in the adjoining sewers and drains. At this point one may leave the reader to his own reflections.

THE POSSIBILITY OF THE EXTERMINATION OF RATS.

Having thus described some of the evils resulting from the presence of rats in Britain, we proceed next to consider the size of the rat population, its natural increase, if any, and the prospect and means of controlling it successfully in future.

There have been many attempts to calculate the reproductive potential of rats. For instance, F. von Fischer, in 1872, concluded that the progeny of a single pair might in ten years amount to no less than 48,319,698,843,030,344,720 individuals. Rucker, more recently, has computed the increase of a pair in five years at 940,369,969,152 rats.

Lantz was not so ambitious; for the purposes of his calculation he assumed the rats to breed only three times a year, and to have average litters of ten. Breeding at this rate uninterruptedly for three years, producing sexes in equal numbers, and with no deaths, the progeny of a single pair at the ninth generation would be 20,155,392 rats.

Zuschlag assumed a pair to have six litters of eight in a year; that the young would breed when $3\frac{1}{2}$ months old, then with equal sexes and no deaths the progeny at the end of the first year would be 880 rats.

Although such calculations are purely theoretical, and although their results, in ordinary circumstances, will never be approached in Nature, they are not extravagant, *qua* the power to reproduce, but are based upon moderate and conservative estimates. In proof we may cite Kolazy's record that two females kept by him had twenty-six litters in a space of thirteen months, and produced 180 young—almost double the number assumed by Zuschlag. We can, therefore, readily understand how the progeny of a few rats introduced to a new country by a ship may, in favourable

circumstances, succeed in overrunning the whole country in the space of a very few years, and how these animals speedily develop into a most serious pest when what may be called the rat resistance of a country is allowed to sink to a low degree.

In 1909 Boelter, after a long series of enquiries, assumed the density of the rat population to be not less than one rat to each acre cultivated, or alternatively one rat per head of the human population. The minimum number of rats inhabiting Britain was therefore put by him at 40,000,000. In the opinion of many, including the present writer, that estimate is a very low one.

Between 1909 and 1916 energetic efforts for the destruction of rats were made by many public bodies and companies throughout the country. One metropolitan body, for instance, by trapping and other means, destroyed in 1911, 9,936; 1912, 10,834; 1913, 13,781; 1914, 12,616; 1915, 11,272; and in 1916, 15,123 rats; in addition many others not identified must have been destroyed by the official cats kept.*

The returns published in respect of rats killed in the City and Port of Liverpool afford similar reading. Here again—and numerous other instances could be quoted—the numbers of rats killed from year to year increase rather than diminish. In purely rural districts it is similar: thus in East Haddington the efforts of the Eastern District Committee of the Haddingtonshire County Council resulted in the destruction of rats as follows:—

For the year ending Oct.	25, 1913	20,798
,, ,,	24, 1914	23,625
,, ,,	23, 1915	25,636

* Dr. Willoughby has records of the destruction of 931,846 rats between the years 1901 and 1916; this number includes rats killed during the voyages or on the fumigation of vessels entering the Thames, as well as those killed in docks and warehouses. He says (*in litt.* to the writer):—"I am not aware of increase [in rat population] in any part of the Port Sanitary District, but suspect it in a few food-store localities which have come into use since the war. . . . I suspect that the Brown Rat is found in less numbers than the Black in certain docks, which I recognize as storage or warehouse docks (as opposed to transit docks), from the fact that a larger number of Black than Brown are brought for examination from these docks. In one dock the proportion of Brown to Black brought for examination in 1916 was Brown 1,265, Black 90; in another, Brown 249, Black 311. In the one dock the 'wild' and 'transit' conditions prevail, in the other the 'warehouse' and 'domestic' conditions. In the one are grass banks (for summer burrowing) and one-storey sheds; in the other granite and warehouses. In the Blacks of the above figures I have included *rattus* and *alexandrinus* (a fair sprinkling of the latter are reported)."

This last case is especially instructive because the extent of the means of destruction employed, as well as that of the area of operations, has remained constant during the three years covered.

If now we may take the number of rats killed as an index of the number of rats living, then we may conclude from such returns that the measures adopted for the destruction of rats up to and including the year 1915 have not resulted in bringing about any absolute decline in the rat population; in fact, the figures suggest that destruction has not even been able to keep pace with the natural increase of that population.

Now, although the war has rightly not been allowed to interfere with the catching of rats in our chief ports, because of the paramount importance of protecting the public health, it has most seriously interrupted and discouraged such work in ordinary towns and in the rural districts. Military service, the manufacture of munitions, and the great rise in wages in the towns have all contributed to denude the country and the towns of that labour which was formerly devoted to rat extermination. The need for enforcing economy in the use of foodstuffs has given rise to a series of regulations, which in effect prohibit the use of all food for bait, and for conveying poison or virus to rats. Such regulations also have therefore played a great part in obstructing or stopping the indispensable work of the rat-catcher. The result is deplorable. From all parts of the country come complaints of a great increase in the numbers of rats present, and of the great damage they are doing to ordinary agriculture as well as to the produce of the allotment holder. Such a result was bound to ensue, even if nothing had been done to assist the rats beyond the temporary cessation of our efforts to destroy them. But the great national endeavour to increase the internal sources of food has benefited rats as well as citizens. The numbers of rats, no less than the numbers of men, depend entirely upon the food supply; and as all classes have become or are becoming producers of food, so in proportion the capability of the country to support rats has grown and will grow. Every new allotment, new chicken-run or rabbit hutch, offers a new niche in Nature for the accommodation and maintenance of the rat. As is shown in the following paragraphs, the rats not only are able to, but must take advantage of these new outlets for their numbers, for with them it is a case of colonize or perish. For our safety it is imperative to find a means of controlling the rat population.

What is the problem to be faced? In order to express it in the most moderate terms possible, let us assume that the rat population of this country on Jan. 1, 1918, was still no more than 40,000,000—that is to say that Boelter's estimate of 1909 still held good at the date in question in spite of the lapse of nine years and in spite of the unfortunate events of the last three years. Let us assume the sexes to be equally distributed. A certain proportion of the 40,000,000 rats will, from one cause or another, have no chance of breeding, and may be thrown out of our calculations at once. Let us assume that 50 per cent. have to be so discarded. That leaves us with 20,000,000 rats, or 10,000,000 pairs, on Jan. 1, 1918, as our capital stock with a chance of breeding. But even breeding rats must die; we will therefore assume that 95 per cent. of our 10,000,000 pairs will die, by equal monthly instalments, in the course of the year. We have thus assumed a natural mortality and waste among the rats amounting to a total of 97·5 per cent. per annum; and by this assumption we have reduced our initial stock of 40,000,000 rats to 1,000,000 in the space of twelve months. This waste is repaired by breeding. Let us assume that each pair of rats, surviving long enough, has six litters per annum, and that each litter contains on an average eight young. As will be seen from the account of the breeding habits given above, both these assumptions are moderate. A certain number of young will die at birth; we will assume that this accounts for 50 per cent.—a high proportion. Of the survivors, many will never have a chance of breeding; we will assume this to apply to 50 per cent. of them, or to 25 per cent. of all born. Those that have a chance of breeding have also to die; and as in the case of their parents, we will assume that natural mortality accounts for 95 per cent. of these effective rats, and we will reckon it from the moment of their birth. Here again we assume a huge waste and mortality probably much in excess of the natural waste. The young rats are assumed to breed first when four months old and at the same rate as their parents; and the assumptions made above are also made in the case of succeeding generations.

In the accompanying table (p. 60) the results of the calculations based upon the above assumptions are given, so far as they concern the effective or breeding stock of rats. From this table it will be seen that our effective capital stock of 10,000,000 pairs on Jan. 1 might be replaced on Dec. 31, 1918, by no less than 41,000,000 pairs, and that in the early days of January, 1919, we

might expect the birth of 12,000,000 pairs possessing a chance of breeding. Further, although it would considerably affect the calculations if they were extended to cover the year 1919, the assumption of three instead of six litters would make comparatively little difference to the figures given for 1918; our 10,000,000 pairs of Jan. 1 might still grow to 32,000,000 by Dec. 31; the cost of keeping them, estimated at £9,224,500 with six litters, would only be reduced by £232,500 if we assumed the birth of the first three litters only.

Such a calculation, although open, it is true, to many objections, suffices to prove that we are dealing with a very formidable problem indeed. Such a rate of increase must very soon lead to disaster if it be not checked; it cannot continue. In normal conditions Nature would and does step in to check it. The natural enemies of the rat—carnivorous mammals, such as weasels, stoats, polecats, martens, cats, and foxes; birds of prey like owls and kestrels; reptiles such as snakes—these, with their food-supply so greatly increased, would multiply in proportion. If, in spite of the havoc wrought by these carnivorous creatures, the numbers of rats continued to increase unduly, Nature's other and more dreadful remedy would assert itself. Food and space are limited; underfeeding and overcrowding would sap the vitality of the rats; the weaker individuals would be attacked by micro-organisms, *Bacillus pestis*, and innumerable others; their stronger brethren would in turn become infected, either by devouring the bodies of, or by receiving parasites from those that succumbed. Pestilence would break out in this way among the rats all over the country, and it would in a very short time reduce their numbers to insignificance.

So much for normal conditions. One of the penalties of civilization is that we deprive ourselves of the assistance of most of our carnivorous allies. Polecats and martens have practically gone, and wild cats with them; domestic cats as a class are not keen on ratting, though there are exceptions; foxes are too mischievous to poultry, and their numbers are strictly limited; weasels and stoats, which do an invaluable service in killing large numbers of young rats (and it should be recognized that young rats are always more numerous and potentially more dangerous than adults) are everywhere persecuted; owls and kestrels are too frequently shot at sight; and snakes no longer count. We have, it is true, our domestic dogs and ferrets. Working with an experienced man, these do a great

execution among rats; but their powers have limitations, and they form no sort of just equivalent for the wild carnivora we have lost.

Even if we still possessed our full quota of carnivorous creatures, it is more than doubtful whether that would relieve us from anxiety in this matter. Our enterprise in engineering and building has provided the rat with a measure of shelter and security infinitely greater than the best that could be afforded it by Nature. Against rats in such strongholds carnivora could do but little.

We cannot, however, deprive Nature of her second weapon: infectious disease is always present, if latent, among rats as among men. But we dare not let Nature invoke disease; for should she do so, that disease will in all probability smite man no less than the rat. For this reason our public health authorities work hard to preserve the rats in good health. As soon as they observe mortality from unknown causes among rats they look for plague; if, as often happens, they find plague, they endeavour to protect the rats of other places by first isolating and then exterminating the infected colony. Biology has sought and is still seeking a disease which will kill rats but be harmless to man and his domestic animals; that search has not yet been rewarded, although results of great promise have been obtained. Promise is one thing, fulfilment another; the disease weapon to our liking may not be fashioned before we have felt the sting of one of those already existing in the armoury of Nature.

What then is to be done? Are we so destitute of resource that we must be content to wait for that punishment inevitably ours if we do not find a method of redressing the balance of Nature so light-heartedly disturbed? The answer to the latter question is simple. Although there is no royal road to such an end, we possess ample means of exterminating the rat if we have the mind to do so. These means, however, will not avail until everybody in this country is convinced of the necessity of using them whenever and wherever possible. There are six indispensable co-efficients upon which the success of whatever means we may adopt will depend; these are organization, co-operation, determination, time, money, and labour—the way of the transgressor is hard. Of course, science may shorten the road for us, but not without further biological research of all kinds. That, however, again costs time and money; and so many have yet to learn that all branches of science are valuable and interdependent, that in reality there are *not* two kinds of science—one called "applied,"

essential, it extracts gold; the other called "pure," quite unimportant, it extracts nothing but facts.

The need for organization and co-operation in rat destruction will appear from the following remarks. The table at p. 60, be its figures right or wrong, fairly illustrates the working of the principle by which the rat population increases in spite of the enormous toll occasionally levied upon it by man. Many more rats are born than can possibly survive; many more survive than can possibly breed. If A has premises, which cannot be or have not been rendered absolutely rat-proof, in a rat-infested area, it is perfectly useless for him to kill rats without the co-operation of his neighbours B, C, and D; the utmost reward for his trouble and expense will be a little temporary relief. For in exterminating his own rats he has created a vacancy for a corresponding portion of the surplus rat population born on the property of his negligent neighbours, and accordingly, in a very short time, A will acquire a new stock of rats. A good instance of this is given us by the officials of one of the great trading corporations of London. They say that, in consequence of their unrelenting persecution and continuous efforts to abolish all shelter for rats, comparatively few of the animals are able to breed upon their premises; in some of their warehouses the numbers of rats caught tend to diminish from year to year, in others they increase. They ascribe the increased numbers to the action of certain local authorities, who permit large rubbish dumps to be formed on lands adjoining the premises in question. In these dumps rats breed in enormous numbers, and for the most part they visit the warehouses merely in search of food. Trapping in these places on a large scale no doubt saves considerable losses of stores, but as regards the rat population its only effect is to give a chance of living and breeding to many individuals who otherwise would not have possessed such a chance.

Further, the County Medical Officer of Health for East Suffolk, reporting upon the steps taken by the county, urban, and rural district councils in regard to the outbreak of rat-plague, says:—"From all parts of the county we hear of the active work undertaken by private individuals. A large amount of time and money has been expended by them in the destruction of rats. They make one complaint, a very pertinent one; it is that their work is of small permanent avail because of the apathy of their neighbours, and this indifference is to be found in the close proximity of, and even within, the areas where the infected animals have been found.

This want of unanimity of action is much to be deplored, and is very unfair to those who have willingly expended much." (**7**, p. 84.)

Such facts lead us to conclude that spasmodic, individual, or purely local attempts at rat extermination can bring no real relief. The work of destruction, to succeed, must be undertaken simultaneously all over the country; it must be systematically done with the approval and co-operation of all; and it must be continued so long as a breeding stock of rats remains in this island. The last point is of essential importance. It may be said at once that the final stage of such a war on rats will be the most difficult and, in visible results, the least spectacular of all; but a premature cessation of our destructive efforts would be followed by a speedy recurrence of the present evil; our money and labour would have been expended in vain.

It is, of course, not within the province of the writer to suggest the means by which a work of such magnitude and importance can be organized or financed, nor how general co-operation can be secured; those are questions entirely for the public and Parliament. The writer has performed his duty by pointing out the urgent necessity for some such action against the rat population; these animals are at once a reproach to civilization and a menace to humanity.

RAT-PREVENTION AND RAT-EXTERMINATION.

The country owes its rat population in the first place to the ports. The ports and the towns feed the rural districts with rats; waterways form natural high roads for rats; human traffic, waterborne and land-borne, greatly assists their dispersal. The key to the problem lies in our towns, for the rural districts can never be kept permanently free from rats while the towns are infested.

The problem is, however, most difficult of solution in the **towns**; because here the rat population attains its maximum density, and finds food and shelter in abundance. Here also our choice of means of destruction is limited practically to traps and to attacks with the help of dogs, ferrets and cats; poison and virus, because of the danger to health which their use involves, can be but seldom used in towns. Preventive measures must play the chief part in towns, active destruction, although most useful when combined with prevention, being quite unable to eradicate urban rats.

The chief **Preventive Measures** are:—

1. Protection of food supplies.

This is of prime importance. All foodstuffs in stores, markets, and shops should be kept in rat-proof receptacles when not exposed for sale. Household larders and the mangers of domestic animals should be carefully protected from rats.

2. Removal and destruction of refuse.

Pending removal, all refuse should be placed in rat-proof receptacles, such as metal bins with tight-fitting lids. Our carelessness in this matter provides nourishment for swarms of rats in every city.

Refuse should be promptly removed and destroyed. The formation of rubbish dumps is a most dangerous practice and should be prohibited; such dumps always afford good shelter and much food to rats; and they frequently become the principal breeding places and strongholds of rats infesting docks, warehouses, and railway goods yards.

3. Rat-proofing of buildings.

All new buildings should be made rat-proof by the liberal use of cement in their cellars and foundations, and by the proper protection of their doors, basement windows, ventilators, and drains. Whenever opportunity presents itself similar protection should be given to existing buildings.

4. Protection of drains.

All drains opening into sewers should be efficiently sealed. Inlets and outlets of stackpipes, etc., should be guarded with wire cages.

5. Fumigation of ships, and protection of quays, railways, etc.

In most ports the Sanitary Authorities now fumigate ships and take steps to prevent rats from passing from ship to shore and *vice versa*.* The importance of such measures cannot be exaggerated, and it is to be hoped that everything will be done to extend or improve their application. Attention should be paid to lighters, barges, and other craft on our rivers and canals.

Wooden stagings and platforms frequently harbour immense numbers of rats; they should be replaced whenever possible by solid structures of brick and concrete.

* All hawsers should be furnished with rat-shields, such as circular discs of metal not less than 4 feet in diameter.

With regard to the **Destruction** of rats in towns:—

Trapping should be done continuously and systematically at all rat-infested places; and wherever possible they should be attacked with cats, dogs and ferrets.

In badly infested areas public **rat-catchers** should be appointed. The position of these men when appointed should not depend upon whether rats remain to be caught or not; if the rat-catcher succeeds in cleansing a badly infested locality his pay should be increased, and it should remain at the higher level for so long as he succeeds in keeping the place free from rats.*

In normal times, when many persons are unemployed, the payment of small **premiums** for each rat caught has good results. This method has, of course, been tried on many occasions in this country from the eighteenth century onwards; its failure here hitherto is partly to be ascribed to the fact that the premium offered was often too beggarly to attract, but chiefly to the fact that such a system was only tried in certain districts and never throughout the country as a whole at any one time. Zuschlag was the first to put such a system upon a scientific basis; after much experiment and agitation his scheme was embodied in the Danish Rat Law, and it worked with good results in Denmark and in other Scandinavian countries. The premium to be paid should be settled independently in each district; its amount must depend upon the state of the labour market and the scale of wages for unskilled labour in each locality. If too low the premium attracts children only; if too high it tempts fraudulent persons to try their cunning. In ordinary times this system is calculated to enlist the services of a large amount of nondescript or casual labour. In Denmark the rats were received at the fire stations; the tails of the rats brought in were cut off by the firemen,† and the latter used them as their vouchers for the money they had paid out as premiums. In certain German towns the system did not work so well; the premium offered was too low, and, what was still worse, the rats were received at the police stations. Those who might have been attracted even by such small rewards did not care to run the risk of visiting the police, for as Zuschlag

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* Proper supervision of such men is, of course, pre-supposed.

† In the interests of the public health it is essential that the whole rat should be surrendered—not merely heads or tails. Without such a stipulation the carcases may become more dangerous than the living animals.

says: "Quand on est sans pain et sans travail, la conscience n'est quelquefois pas tranquille."

In all towns occupiers of rat-infested property should be obliged to notify the local authority of the fact that their premises are infested with rats. For the purposes of certain trades—*e.g.*, the catering trade—the use of rat-infested premises should be forbidden. Some years ago the writer had much personal experience of two rat-infested eating-houses situated in a main street of the City of London. These were next door to each other; the one, more expensive, catering for professional men, was in a comparatively modern building; the other, a cheaper place, was in a house dating from the seventeenth century. Rats swarmed in both of them, doing great havoc to the stores. Each restaurant blamed the neighbouring establishment for its rats, and each had an extensive underground kitchen. Food was frequently contaminated; rat dejecta not unfrequently appeared in portions of vegetables, jam, or stewed fruit; and rat fleas were by no means uncommon in cornflour blancmanges and suet puddings. In the evening hordes of rats came up into the public rooms from below, as the shops were closing. On one occasion workmen, who had been painting the walls of one of the establishments during the night, informed the writer that the rats had been so numerous upon the floor that the men were afraid to descend from their trestles. Dogs were kept in both premises, and on ordinary nights had the run of the shops; these killed many rats each night, and entrails of their victims were sometimes tossed by the dogs into the urns on the counter. Despite the rats, the writer, being a chess player, remained a customer at one of these shops until a new building was erected across the road; that building was of the rat-proof type and its ground floor and basement became a restaurant. It has been so used for some ten or fifteen years now, and it has remained free from rats, although these pests are quite common in adjoining and older houses. In our opinion no refreshment licence should be granted in respect of any premises not certified to be free from rats and to be rat-proof.

Rats, of course, cannot be attacked with equal success at all places in towns. Sewers are usually infested, and it is naturally difficult to cleanse them of rats. In those of Paris a means of electrocuting them has been introduced; a live wire is supported at a height of a few inches, and dainties are hung at intervals above it. When a rat attempts to snatch a morsel it puts its paw

upon the wire, and its existence is suddenly terminated. Boelter states that the London sewers in the neighbourhood of Soho are now free from rats because of the quantities of petrol which find their way into the drains from the motor works of that locality.

Besides petrol, the following substances can be introduced into burrows and runs to induce rats to exchange secure quarters for those in which they can be more readily attacked :— Gas tar, chloride of lime, caustic potash, strong solutions of ferrous sulphate ; thin whitewash may be poured into burrows ; and freshly-slaked lime placed dry in the burrows or runs is effective.

In the **Country, preventive measures** of the kind suggested above for towns should be adopted whenever and wherever an opportunity presents itself. Stacks should always be made rat-proof where possible ; this may be done by building them upon a platform supported on piles ; the platform should be raised at least 3 feet from the ground, and the piles should be furnished with metal rat-guards of at least 4 feet in diameter. Efforts should be made to render farm-buildings, stables, cow-houses, barns, slaughter-houses, mills, and rural railway stations rat-proof ; and great attention should always be paid to the necessity of keeping the food supplies of domestic animals from contact with rats. Preventive measures are naturally far more difficult in the country than in the towns ; nevertheless, they are important, and wherever they can be adopted they will amply repay the expense and trouble involved.

On the other hand, **destruction** of rats is comparatively simple in the rural districts and far less costly ; for instance, each rat taken by one London body costs on an average 1*s.* 8*d.*, while in Haddingtonshire the average cost was only $3\frac{3}{4}d.$; but as pointed out above, the destruction must be general and carried out with the approval and co-operation of all. Well-organised rat clubs or the payment of well-chosen premiums will no doubt do great good in securing the services of the younger and the poorer inhabitants. But every landowner and farmer should recognize that it is his duty, in his own interests no less than in those of the community, to kill the rats and destroy their breeding haunts on his property or holding ; that if he fails in this duty he simply negatives the results obtained by his more enlightened neighbours.

The fullest protection should be accorded to all Stoats,* Weasels, Owls, and Kestrels. They are most valuable allies and destroy large numbers of rats. It is not a sound argument to object, as some do, that a weasel will not attack a full-grown rat; weasels do a better service than that—they kill large numbers of young rats, and young rats are far more numerous than old ones, and potentially far more dangerous. If these beasts and birds of prey occasionally help themselves to a young game bird or a rabbit it is not of much consequence; the rats they have destroyed and will destroy, if unmolested, would have done and will do, if not destroyed, far more damage of that kind. In fact, many of the crimes laid at carnivorous doors are crimes committed by the rat.

Poisoning should be done once or twice a year—in the spring and in the late autumn. March is said to be the best month for this, because food is short and the rats will take the poisoned baits readily. Arsenic is recommended by one very experienced rat-catcher as the best and safest poison, because in the small doses necessary to kill rats it entails little risk to domestic animals; if they find and eat the body of a rat so poisoned the small quantity of arsenic in the body is said to act upon them merely as a purgative. On the other hand, the United States Public Health Service is convinced, according to Lantz, "that arsenic is a very unreliable rat poison." Barium carbonate is a very good and probably the safest poison; it has the merit of being tasteless and odourless when conveyed in a proper medium. A proprietary article—"Sanford's Poison"†—has recently been highly praised by Mr. Sharpe, in the *Field*. Strychnine and phosphorus are also used effectively; but they are most dangerous, and must be used with the greatest caution.

Poisoned baits should always be placed well within the burrows and out of the reach of other animals; by this means also the risk of a rat carrying a bait off and leaving it in an exposed place is diminished. Where desirable to poison rats on a feeding ground away from their burrows, as in a barn, it is necessary to convey

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* This recommendation to protect Stoats and Weasels does not, and will not, meet with the approval of all; in the writer's opinion it is one of the most important measures, not only against Rats but against Mice and Voles (*see* pp. 43–47).

† Dr. Manby informs us that phosphorus is the poisonous ingredient in "Sanford."

the poison in loose materials (like meal) which cannot be carried away, and also to prevent other animals from gaining access to the poisoned food. Rats commonly become thirsty after poisoning, and make their way to water; it is, therefore, very necessary to safeguard wells, etc., before commencing poisoning operations, otherwise bodies of rats fall in, and their decomposition may have serious consequences for the consumers of the water.

Outdoor rats can be poisoned in their burrows by means of gases—such as carbon bisulphide, sulphur dioxide, or chlorine. Carbon bisulphide is the most convenient one to use out of doors, but being very inflammable it requires great care in handling. A piece of tow, cotton-wool or other absorbent material is saturated with the liquid and pushed into the burrow as far as possible; the mouth of the burrow is then tightly closed with earth. Although fumigation (preferably with sulphur dioxide) is most useful on ships, it is not so effective in buildings owing to the difficulty of confining the gas used; and if effective indoors, the decomposition of the dead rats in their inaccessible hiding-places is apt to entail unpleasant consequences. After poisoning or fumigation the burrows should always be run with gas-tar.

In low-lying districts burrows may sometimes be flooded with good effect; many full-grown rats perish by drowning, and, what is more important, many litters of young can be thus destroyed.

Virus of one sort or another is occasionally effective. Such bacteriological preparations are, however, costly, and they require considerable skill in their use. Their virulence varies, and disappears more or less rapidly on exposure to light and air. The disease communicated usually propagates itself from rat to rat very slowly; and, what is worse, less than fatal doses render rats immune. The harmlessness claimed for all towards animals other than rats and mice is, at least in many cases, open to question. Although bacteriology may furnish us any day with an efficient means of destroying rats at will, it cannot be said to have done so yet. Not one of the many preparations sold can be recommended as a safe and thoroughly reliable means of destruction.

Trapping should be done at all times continuously and systematically, and special attention should always be paid to watercourses and drains. Steel spring traps are the best for general use, and when used out of doors they should be set early in the day; they should be regularly visited at dusk, late at night, and early in the morning. Various baits may be used. The trap

should be handled as little as possible in setting, and the hands should be well rubbed with earth before touching it. Rats can often be taken in their runs by means of unbaited traps. It is often useful to bury the traps under a thin covering of earth, chaff, or other loose materials lightly sprinkled over them with a sieve. Many useful hints on trapping may be found in the papers recently published in the *Field* by Mr. Sharpe (January to March, 1918).

In some cases, as where a run passes along a wet ditch, or where the rats show themselves to be very shy, rats can be readily caught by traps set and covered by a thin stratum of water; traps so covered are not betrayed by their odour. Where traps thus set are baited, as when used indoors, the bait hangs just above the surface of the water. A method of this sort has been described by an American writer (**10**), and more recently (and quite independently) by Mr. Sharpe in the *Field*. Mr. Sharpe supports the trap on three nails in a gap cut in a wooden platform, which is placed just under the surface of the water in a tank or in a hollow dug in the bed of a ditch. When the trap is sprung it is thrown off the supporting nails and sinks with the trapped rat down into the tank or hollow beneath.

In barns, granaries, and other places large numbers of rats can be caught alive by box-traps or strong wire cage-traps, if these are properly baited and concealed. Pitfalls also, such as large vessels sunk in the ground, or barrels with pivoted lids, are often very effective when properly baited; in these traps a decoy rat may be placed with advantage; a female immediately after she has given birth to a litter makes the best decoy imaginable. A very neat and inexpensive contrivance, the invention of two poor Swedes, is described by Zuschlag. A wooden stockade about 3 feet 6 inches high is erected so as to enclose a triangular space, of which each side is about 12 feet in length. In one of the sides is a gap 18 inches to 2 feet wide; this gap is closed at will by means of a heavy slide held up, when the trap is open, by a cord and pulley. In the base of the side opposite to the gap is fitted a funnel, of wide enough bore to admit of the passage of a rat; the funnel opens into a sack placed behind the stockade. The inner side of the stockade is smooth, so as to give as little foothold as possible to rats attempting to climb out; and old iron plates or tiles are placed so as to overhang the edge of the stockade, inclined at a suitable angle to prevent the rats from leaping out. The trap

is baited with any attractive stuff, such as old bones or a dead dog; the slide is opened and the rats are allowed to regale themselves freely for a time. Later the man who is to work the trap secretes himself; when he judges that enough rats have entered the enclosure he releases the cord controlling the sliding door. The operator and his comrades then hurry to the trap and scare the rats by beating its sides; the rats, unable to climb or jump out, soon discover the funnel and pass through it into the sack. When the sack is full a board is dropped over the mouth of the funnel, and the men beat the sack with shovels until all the rats within are killed. With this trap the inventors caught upwards of 5,000 rats in a very short space of time. In trapping, however, far less depends upon the trap than upon the trapper; the good man will take rats with the most primitive contrivances if put to it; the unskilful man will be unable to use the best.

Large numbers of rats can be killed by means of men and dogs towards the close of reaping, mowing, and threshing operations, if care has been taken to prevent the escape of the rats. In the case of cornstacks this can easily be done by surrounding them with a temporary fencing of rat-proof wire-netting placed at a distance, sufficient to prevent the rats jumping over it from the stack.

Many rats can also be killed in their runs and elsewhere at night by the flash-light method; thus they frequently come to the outer surface of ricks at night. If a strong light be suddenly flashed upon them, the rats are temporarily dazed, and they can be whipped off to the ground, for dogs to deal with, by a man armed with a long stick.

If a general campaign against rats should be organized throughout Britain, it should proceed on some such lines as the following. The country should be divided into districts, each having as far as possible water for its boundaries. Work in each district should commence at the boundaries and proceed gradually towards the centre; the more the work is supplemented by individual effort the more effective it will be; and the full co-operation of all landowners and farmers will be essential. Systematic operations (poisoning, fumigation of burrows, etc.) should commence immediately after the harvest, and they should be continued into the spring, the ground being traversed more than once if possible. Trapping, of course, should be done throughout the year. With regard to labour, a correspondent states that it takes one man to every 2,000 acres to conduct

trapping operations properly; on this estimate between 20,000 and 30,000 men would be required for such work in Britain. But if the work were properly organized, and one could count on the co-operation of all sections of the community, far fewer men should suffice. Thus, in East Haddingtonshire three rat-killers were employed throughout the year; each man was allotted a district of from twenty-five to thirty farms, and lived in the centre; each worked gradually from the boundary of his district towards his home. While the best trappers are usually retired gamekeepers, any man of ordinary intelligence can become proficient with a little training. It is suggested that rat-catching offers a good field of employment for many disabled soldiers and sailors.

In a general campaign of the kind suggested, the men engaged must be paid by settled wages and not by premiums on the numbers of rats caught. If one pays so much a rat, the rat-catcher will leave a farm as soon as rats become scarce, and before he has finished his work, for another which promises a bigger bag. In a short time the condition on the first farm will be as bad as before.

2. HOUSE MICE. Genus MUS.

Only one species of this genus inhabits Great Britain :—

Mus musculus. The Common House Mouse (Fig. 1).
Size small; general form slender—like a Black Rat in miniature.

Fig. 1.—House Mouse (*Mus musculus*).
(Natural Size.)

Ears moderately large, covering the eyes when pressed forward, clothed almost everywhere with short fine hairs.

Tail about as long as the combined length of the head and body; frequently longer, rarely shorter.

Feet short and broad. In the hind-foot a small supplementary pad is present on each side near the lateral margins of the pads at the bases of the innermost and outermost toes.

Fur soft, intermixed with grooved bristles as in the rats, but these bristles are too slender to affect sensibly the quality of the coat.

Teats: females with ten mammae, three pairs on the chest, two pairs towards the groin.

Colour variable.

Indoor specimens are usually dusky grey above, more or less darkened by slate or black along the middle of the back, and gradually paling on the sides to the ashy grey of the underparts; ears brownish; feet dusky above, not contrasting with back; tail dull brown, occasionally lighter below than above.

Outdoor specimens have the hair-tips often more or less extensively bleached to a yellowish brown; so that such specimens usually appear more or less sandy or tawny in colour.

Albino and melanistic specimens are not uncommon. In domestication numerous varieties of colour and pattern have been produced as fancy breeds.

Weight of adults normally about 16 grammes, or slightly over $\frac{1}{2}$ ounce.

Measurements in millimetres :—

Head and Body.	Tail.	Hind-foot, without claws.	Ear, from base.
70 to 100	70 to 102	17 to 19·4	11 to 16

In its outdoor dress this animal may sometimes be confused with the Long-tailed Field Mouse; its shorter, broader, and dusky feet, and smaller and less protruding eyes are diagnostic. The skull and teeth (Figs. 5 and 6, pp. 57–59) are so peculiar that they cannot be confused with those of any other British species.

History.—Like the rats, the House Mouse appears to be of Asiatic origin. Its arrival in Europe dates, however, from a very remote period. It was well known to the ancient Greek and Roman writers, and it figures in our own records and literature for more than one thousand years. On certain islands, such as St. Kilda and the Faeröes, it has existed long enough to develop

local races, sufficiently different from their parent race to be regarded by many naturalists as distinct species. Over much of continental Europe, particularly in the warm Mediterranean region, a somewhat smaller form is found living a perfectly wild life far from houses; this outdoor mouse is called *M. spicilegus*, and Miller and others regard it as perfectly indigenous.

At various times remains of the House Mouse have been recorded as fossils from British Pleistocene deposits, but the writer, well acquainted with this branch of the subject, thinks that no satisfactory evidence of the presence of this species in Pleistocene Europe has as yet been found. In his view, the House Mouse probably came to Europe from Asia with a people not older than the Neolithic, and then spread all over Europe, including the islands. While it continued to infest the habitations of man in all places, individuals found that they could in certain localities live quite well out of doors; these, therefore, resumed a wild habitat, and their descendants have developed into the peculiar local or wild races mentioned above. All mice are plastic animals, and the House Mouse is no exception to the rule. To-day, in America, where no *Murinae* are naturally present, the House Mouse is living in the fields as well as in the houses, and it is developing local races or sub-species; indeed, in South America it is tending to lose its posterior molars, and if those teeth were constantly absent, and we were ignorant of its history, the South American animal would be classed by many zoologists as belonging to another genus.

General Habits.—The general habits of the House Mouse resemble those of the Black Rat. It is a good climber and jumper; it swims well, but rarely takes to water voluntarily. Its senses, with the possible exception of sight, are acute. Like rats, it shows a propensity for following a beaten track, and of this advantage can be taken when trapping is being done. Its nest of soft materials is placed in any convenient recess—in walls, behind skirtings, under floors or steps, in bookcases or other articles of furniture, and in many other places.

Its food comprises every description of human food, and even tobacco; grain of all sorts and seeds of many descriptions are readily eaten.

Breeding Habits.—House Mice are very prolific; they attain sexual maturity when three months old. The sexual season

of the females is a very long one. The period of gestation is normally from nineteen to twenty-one days; it may in certain circumstances be shortened to twelve or thirteen days. "Heat," not lasting longer than twelve hours, rapidly succeeds parturition. Many litters are born throughout the year, but fewer in the cold months. The number of young per litter is between five and six, but it may be as many as nine or as few as two. The young are born blind, naked, and pink; they grow rapidly, and are able to leave the mother in less than three weeks.

Economic Importance and Relation to Public Health.—Few houses in Britain are permanently free from House Mice. When the number present is small they do comparatively little harm, and many people rather welcome the occasional and sudden appearance of the little beast on their hearths. But when a large colony is present it is quite a different matter. The mice become then an intolerable nuisance, eating large quantities of our food, spoiling far more with their droppings, and tainting every place and thing with which they come in contact with their strong and unsavoury odour. Birdcages are robbed of their seed; linen, clothing of all kinds, and books are attacked, and holes are gnawed in the woodwork in all directions. Traps and cats are now brought in to fight the pests; the members of the household grow more careful in securing the food supplies and in placing other things beyond the reach of the mice; in a short time, as a rule, the premises revert to their normal condition. The loss occasioned by such a visitation is often quite considerable.

In shops, warehouses and granaries, and on farms House Mice are normally more abundant; in such places they often do great damage and cause much loss. In the materials stored they find abundant food and shelter, and accordingly they breed at an amazing rate.

Most countries are visited periodically by "mouse plagues." These plagues usually develop in summers following mild winters and previous seasons of great plenty. Such favourable conditions of climate and nutrition favour the mice by decreasing the normal natural mortality, and by increasing the size and the frequency of the litters born. Usually all the species of *Muridae* inhabiting the district affected contribute to the formation of the "mouse plague." Thus in Britain what are called "vole plagues" are marked not merely by a great increase in the number of voles present, but

great hordes of Field Mice and outdoor-living House Mice are developed simultaneously. Such a plague brings ruin and devastation to the countryside; the ground is riddled with holes, the crops and many young trees utterly destroyed. The plague may run a course of several months, but sooner or later disease breaks out among the rodents, they succumb in millions, and in a short time their numbers are once more normal, or sub-normal, and the plague is at an end.

Recently South Australia and Victoria have been visited by a very severe "mouse plague," the worst ever experienced in Australia. The principal species involved was the House Mouse, but it was assisted not only by various native species but by battalions of rats as well. The plague developed in the bush as well as in the wheatland in 1916 and 1917, after two abnormally heavy harvests. The wheat grown was sold to the British Government, and the grain was stacked in bags ready for shipment. Shipping was cut off and the stacks remained unprotected from a possible attack by the rodents. As cold weather approached the mice invaded the stacks; an eye-witness of the result says:—"The wheat stacks instead of being as orderly as a brick wall are now evil-smelling heaps of wheat, mice alive, mice dead, and rotten bags." The damage done to the wheat is estimated to be well over £1,000,000; what is worse, much of that which has been re-bagged is in an indescribably filthy condition. The mice were in billions. One farmer put down poisoned meat in his house, and next morning he picked up 28,000 dead on his verandah, and he added that he only stopped then "because he was tired." At one wheat-yard 70,000 were killed in an afternoon; these must have weighed about one ton. Myriads died from a disease, in appearance somewhat resembling ulcerative syphilis; and the men trying to cleanse the stacks contracted a kind of ringworm. Large quantities of hay were also ruined, and horses fed upon the dirty residue were killed. Of course, much other property was injured; thus, in a grocer's shop at Port Lorne, South Australia, many packages of lead pencils were devoured—the flavour of the wood appealing to the mice; and they ate the leaden bullets out of some hundreds of cartridges. Here also the seaweed on the beach was swarming with mice.

As regards their general relation to the public health, many of the remarks made above as to rats will apply to mice equally well. In certain circumstances they convey plague, and there is

no doubt that they help in perpetuating trichinosis among swine. Mice, when present in such numbers as in the Australian plague just discussed, with their parasites and diseases, must constitute a grave danger. Quite apart from the risk of disease being conveyed by the living mice, there is a serious peril of water becoming contaminated by their putrefying bodies. The use of grain fouled by them, for human food or even for that of domestic animals, is an extremely risky proceeding—unless, indeed, really efficient means of cleansing and sterilizing it can be devised.

Control of the Mouse Population.—Should we succeed in exterminating or greatly reducing the rat population of this country, we shall in all probability disturb the balance of Nature still further in favour of the House Mouse and our other small *Muridae*. The presence and competition of rats greatly diminish both the food-supply and the space available for mice; remove the rats, and there will be nothing to hinder the steady natural increase in the numbers of mice until the latter have filled up the vacancy left by the rats. If, therefore, we fail to adopt appropriate measures against mice at an early stage in our campaign against rats, we shall find ourselves confronted, in due and rapid course, with a mouse plague.

The steps to be taken against mice are similar to those recommended against rats. The chief of them are the following:—

1. **Protection of food supplies.**

All food, whether of man or beast, should be kept, as far as possible, in mouse-proof receptacles.

Unprotected accumulations of edible refuse should never be permitted.

2. **Diminution of the available shelter for mice.**

Rubbish heaps of all sorts should be abolished.

Effective rat-proofing of buildings will render them mouse-proof to a considerable degree.

Mouse-holes should be stopped wherever possible; for this purpose many expedients, such as filling with cement and broken glass, or running with gas-tar, are available.

3. **Destruction of mice.**

Indoors and about houses this is best accomplished by means

of cats and traps. Mice are not, as a rule, suspicious of traps; almost any trap and any bait will take a mouse. In places where there is an abundance of attractive food it is usually well to bait the traps with a delicacy rare in the locality; for instance, cheese may be a good bait in a fishmonger's shop, while fish might be irresistible to the mice of the cheesemonger.

4. Protection of the natural enemies of mice.

Many birds and beasts prey upon mice. The most important in this respect are owls, of all species, and weasels; these creatures should be most carefully protected. It should be recognized by all interested in agriculture that they have no better and no stronger friends than these. Everybody on the countryside, from the squire to the schoolboy, should be taught to look upon the wanton destruction of an owl or a weasel as one of the blackest crimes possible amid rural surroundings.

3. THE BALANCE OF NATURE AND THE PROTECTION OF CARNIVORA.

During the passage of this work through the press, the recommendation that Stoats and Weasels should be fully protected (p. 33) has met with some adverse criticism. In making that recommendation the writer is fully acquainted with the views commonly held by gamekeepers;* and he is perfectly well aware that the majority of them will disagree with him.

The recommendation may be supported by an appeal to first principles, so well known that to many it will seem unnecessary to recite them here; the necessity to recall them arises from the fact that apparently they are forgotten sometimes, when dealing with questions of this kind. Besides, a short statement as to what is meant by the "Balance of Nature" may not be unwelcome to the reader without technical knowledge.

If any organism were allowed to increase at its natural rate of multiplication unchecked it would speedily fill the whole surface of the globe to the exclusion of all other beings. Each species is kept in check primarily by having to compete for space with all other species; apart from innumerable other factors, this alone is

* For recent expressions of such views, *vide* correspondence in *The Gamekeeper*, December, 1917, February and May, 1918; also GUNTHER, pp. 53 and 63.

sufficient to control the numerical representation and distribution of plants. All animals derive their sustenance from plants, either directly or indirectly, or in both ways.

Each country has its own geological and geographical history, as well as its own climatic conditions; further, climate and soil vary with the district. On all these things the nature of the vegetation depends; they determine chiefly what species of plants *may* occur, and which of these will thrive. These things, and the plant-life they control, determine further what animals *may* live, and which of these will prosper in a given locality. All species, be they animal or vegetable, are doing their utmost to feed, grow, and reproduce their kind. The result of all these conditions and forces is that each individual or species reacts, to a greater or lesser degree, upon all other individuals or species brought directly or indirectly in relation with it; its existence and activities may favour, may hinder, or may both favour and hinder the existence and activities of other organisms. In this way plants and animals, and the individual species of each kingdom, are everywhere so closely adjusted to each other that they might be likened to the cells of the honey-comb of the hive-bee; but whereas in the honey-comb we find space filled with a number of similar simple geometrical forms of one magnitude, in the case of organic nature we must imagine space to be filled with an enormous number of figures of diverse form and size. No element can be added to or taken away from such a complex without causing a more or less far-reaching disturbance of the whole. There may be thousands of links in the chain of cause and effect necessary to determine which of two species of mouse, for example, shall predominate in a given locality; so far as human intelligence is concerned the complexity of that chain is infinite.

Every district normally contains the full number of small mammals and birds it is capable of supporting; what that number is depends upon what species are present and the relative proportions in which they occur; these factors in turn depend upon the conditions named above. But many small mammals and small birds are characterized by a high fecundity; and in each year each of such species produces far greater numbers of young than are necessary to maintain the normal stock; if over-population, with all its attendant evils, is not to ensue, the surplus must be removed—and in normal conditions it is removed. The chief destructive agents are ACCIDENTS, such as misadventure, sickness,

or the attacks of enemies (*e.g.*, carnivora and parasites), the effects of COMPETITION and overcrowding, and, above all, the WEATHER, with its great powers of inflicting injury upon any species, either directly or indirectly (as by curtailing the food-supply). These operate, singly or in combination, at all times on individuals of all ages; accidents and competition press most hardly, perhaps, upon embryos and young; the weather destroys chiefly in winter and spring.

The precise mode in which the surplus is removed varies with the species. Despite the heavy toll levied by accident and competition, free-living creatures, like small birds, usually have a large surplus at the end of summer; and that surplus must be removed by the severe weather of the following seasons. On the other hand, more or less earth-bound animals, like the *Muridae*, with their habits of constructing warm nests in dry burrows and of amassing stores of provisions, are enabled to withstand all but the most severe weather. In their case the surplus must be removed chiefly by accidents and competition. Their habits render small rodents the easiest of prey; in fact, they form the staple food of every one of our carnivorous mammals, with the exception of the Otter. Foremost among rat- and mouse-killing mammals are the Stoat and the Weasel; working incessantly, they kill far more than they devour; many mature and healthy rodents fall to them, but the young just leaving the nest, with such adults as are weak and sickly, form the great majority of their victims. Among British birds the Barn Owl, Short-Eared Owl, Long-Eared Owl, Tawny Owl, Common and Rough-Legged Buzzards, Kestrel, Rook, Carrion and Hooded Crows, Raven, Magpie, Heron, and some Gulls may be enumerated as more or less important rat- or mouse-killers; indeed, in this respect the importance of the Owls and Kestrel can hardly be over-estimated. The stronger and more efficient the carnivora (including in that term all the animals which habitually or occasionally prey upon rats and mice), the more completely and automatically will the surplus rodent population be removed as it arises.

In a well-balanced or natural fauna, carnivora will never extirpate the species upon which they feed; the prey is secured only by work; and physiologically it costs more than it is worth to secure the prey when it becomes scarce. Herein lies the chief natural check upon the numbers of carnivorous animals; in addition, carnivorous species prey upon each other when opportunity offers.

It is true that a Fox, if not prevented, will quickly kill every bird in a pheasantry or hen-roost to which it gains access; but this does not affect the principle—pheasants and hens do not enjoy, in this country, the natural protection they require; in their own homes, as wild birds, they are beset with foes, but nevertheless the stock survives.

The high fecundity of small rodents has been developed apparently to enable them to survive the many attacks to which they are exposed; in purely natural conditions and in average seasons it is probably not excessive for that purpose. The precise rate of breeding, however, is dependent upon the food-supply and the meteorological conditions to a very large extent. When both are favourable to the rodents, they multiply at an amazing rate, and the carnivora (of all kinds), even when abundant, may be unable to remove so large a proportion as usual of the surplus produced. If the ensuing winter and spring be mild, part of the surplus will remain over to the following breeding season; and should one or two years of this character succeed each other the inevitable result will be a "Mouse Plague." The development of such a plague involves necessarily great monetary loss to the rural community, and at moments such as these it might lead to national disaster. The plague cures itself in due course by starvation and disease among the rodents, but the cure may bring with it a deadly threat to human health. The risk of Mouse Plague developing is continuous; by carefully preserving our carnivora (Mammals and Birds) in due numbers we minimize the risk and ameliorate the evil when a plague happens. The weather may be lenient to rodents, the carnivora never.

Enough has now been said, perhaps, to justify the assertion that carnivora in general, and Stoats and Weasels in particular, are among the best friends the British farmer and the public at large possess. But a special word has to be addressed to the game-preserver pure and simple. He must not forget that a carnivorous palate is not the exclusive property of carnivorous animals properly so called; the development of such tastes is merely a matter of opportunity and competition; squirrels, for instance, are carnivorous whenever and wherever they get the chance. The Brown Rat is on occasion almost as bloodthirsty as the Stoat; if Stoats and Weasels were exterminated, the numbers of this species would increase very rapidly; as a consequence large numbers of them would be obliged to assume the carnivorous *rôle*

of their banished foes; in such a case their high fecundity would make them most formidable; game and poultry would suffer immediately, and to a far greater extent than they have ever done from all our living carnivora combined.

It is open to question whether entire immunity from attack by carnivora is a good thing, in the long run, for game. Be that as it may, the preservation of a sufficient stock of carnivora is of vital importance to the welfare of general agriculture and the national interest. If the continued existence of predatory animals be really incompatible with game preservation—so much the worse for the latter.

With all the foregoing considerations in mind, it may be safely asserted that not one of our living native species of mammal or bird should be persecuted to extinction; each has to play its part in maintaining the balance of nature in this realm; and the present state of knowledge does not warrant a belief that any member of the native fauna may be safely dispensed with. It may be necessary to check the undue increase of certain species from time to time, to set bounds to their wanderings, and to protect our possessions from their ravages; but that is all. The projected extermination of the Brown Rat, Black Rat, and House Mouse, in Britain, is justifiable biologically solely upon the ground that these three species are alien; but just because they are now so well established here, the extermination of the Rats, without due precautions, may lead to serious trouble with other species, as suggested at p. 42. As a parting word to the agriculturist it may be said that the less he persecutes the wild fauna, the better off he himself will be in the long run. Everything worth having costs something, and a wild fauna is no exception to that rule. A reasonable burden must be borne on account of each species involved; if that burden be refused we may have to shoulder a heavier one.

I would take this opportunity of confessing my great indebtedness to the little book by the late O. Winge, cited below; first published in 1886, a second edition appeared in 1911, furnished with a preface and notes by the author's brother Dr. Herluf Winge, the great naturalist of Copenhagen. If this book were translated it might be read with profit—though not always with pleasure—by all interested in the welfare of Rural Britain, and particularly by those who doubt the value of carnivora, or who think, for example, that the destruction of such "vermin" would lead to a great increase in the numbers of "useful" insectivorous birds.

4. NOTES ON STRUCTURE AND CLASSIFICATION OF THE *MURIDAE*, WITH A KEY TO BRITISH SPECIES.

In these islands everybody is familiar with the general appearance of a rat or a mouse; and this familiarity has often resulted in the names "rat" and "mouse" being applied, in consequence of superficial resemblance, to animals which in structure are very different from true rats and mice. Properly these names can only be given to mammals of the order Rodentia; and then not to all rodents, but only to such species—and there are many hundreds of them—as belong to the family *Muridae*. We thus learn that in dealing with the rat-like and mouse-like creatures of the world it is not sufficient merely to note their differences or agreements in colour and general external form; in order to determine their true zoological position we must examine their anatomy in greater or less detail, paying particular attention to the structure of their skulls and teeth—since these organs furnish highly important characters.

In all *Muridae* the clavicle or collar-bone is well developed, and the tibia and fibula, the two bones of the lower part of the leg, are, to a great extent, fused together. In most genera the thumb is rudimentary. In the **skull** (Fig. 2) each frontal bone lacks a postorbital process; each zygomatic arch is formed chiefly by the zygomatic process of the maxillary and squamosal bones, the jugal being reduced to a mere splint between the two and not articulating with the lachrymal bone in front; the lower root of the maxillary zygomatic process is flattened into a large more or less vertical plate of bone, which forms the outer wall of the infraorbital canal and gives attachment to that part of the great masseter or cheek-muscle, which is chiefly concerned in pulling the lower jaw forwards in the important work of gnawing. The infraorbital canal is large and shaped like a comma; its lower and narrower part transmits the sensory facial nerve and vessels, while its upper and wider portion lodges a slip of the masseter muscle. There are never more than sixteen **teeth**. As in all other rodents (excluding the hares and their allies), four of these teeth are incisors and are placed, one on each side above and below, in the anterior ends of the jaws. These teeth (Fig. 2 **D**), as the instruments by which the characteristic gnawing function

is performed, are highly modified. Each has a thick plate of hard enamel on its anterior surface, but the relatively soft dentine is exposed for a greater or less width on the posterior side; conse-

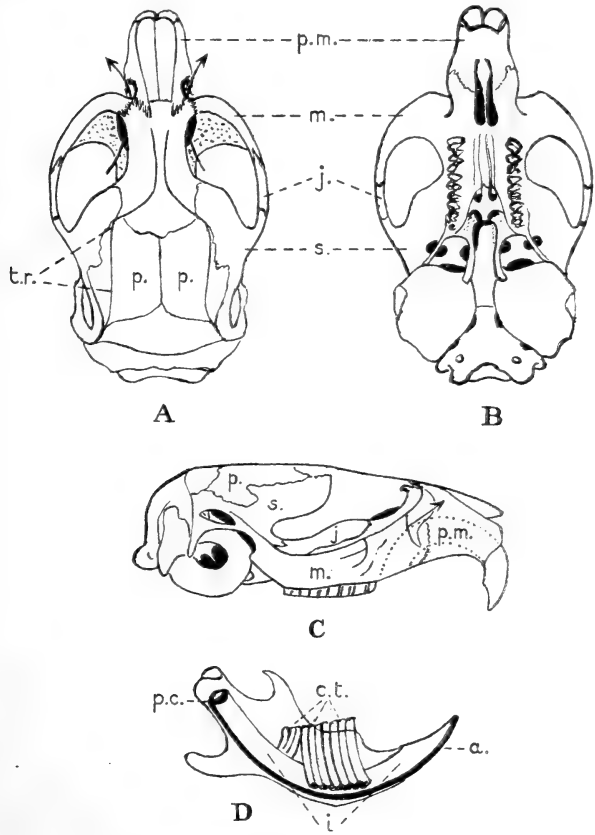

FIG. 2.—FIELD VOLE (*Microtus agrestis*), skull enlarged.

A. Dorsal, **B.** ventral, **C.** lateral views; *p.m.* premaxilla, *m.* maxilla, *j.* jugal, *s.* squamosal, *p.* parietal, *t.r.* left temporal ridge; arrows in **A.** and **C.** pass through infraorbital canal; dotted lines in **C.** indicate course of upper incisor. **D.** right ramus of lower jaw dissected, *i.* the incisor, *a.* its anterior enamel, *p.c.* its pulp-cavity, *c.t.* the rootless molars.

quently with wear the tooth develops and maintains a chisel-like cutting edge. The shaft of each upper incisor forms a large segment of a small circle and passes back through the premaxilla into the maxilla, where it terminates near the anterior molar;

that of each lower incisor forms a smaller segment of a much larger circle and proceeds backwards beneath, or beside, the roots of the cheek-teeth, to terminate in the ascending portion of the mandibular ramus, behind and to a greater or less extent above the level of the molars. The base of each incisor is hollow and open; in life the cavity lodges the dentinal pulp from which the tooth is developed; growth is continued throughout life and the tooth is gradually pushed forwards. Under normal conditions, in adults, the growth and forward movement of the incisors take place at a rate which exactly compensates the loss by wear suffered at the working end. Separated from the incisors by a long toothless interval, or diasteme, are the cheek-teeth; of these there are never more than three on each side above and below, and the anterior one in each jaw is always considerably larger than those behind it. In many forms the posterior tooth is greatly reduced, and in some it is normally absent. The great relative size of the front cheek-teeth is probably due to their position in the jaws, for they are placed just at that point where the combined activities of the temporal and masseter muscles produce the greatest pressure between the upper and lower tooth-rows.

Now the characters described above, with others too numerous to discuss here, are shared by all *Muridae*; any animal showing such a combination of characters would be entitled to a place in this family; and it would in ordinary language be described, according to its size, either as a "rat" or as a "mouse." Zoologists, however, tend to restrict still further the use of these names; they have divided the *Muridae* into several sub-families, of which the principal are the *Microtinae* or Voles and Lemmings, the *Cricetinae* or Hamsters, and the *Murinae* or true Rats and Mice. The leading character of each of these sub-families is seen in the cheek-teeth,* and for our present purpose they may be sufficiently distinguished as follows:—

Cheek-teeth with tall prismatic crowns, in most genera persistently growing and rootless; their grinding surfaces, except when quite unworn, flat and displaying a pattern of more or less alternating triangles (Figs. 2 **D** and 4 **B–D**). Microtinae, or Voles and Lemmings.

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* To examine the molars or cheek-teeth of *Muridae* in recently caught specimens it is only necessary to cut as deeply as possible into the angles of the mouth with a pair of scissors; the mouth can then be easily opened.

Cheek-teeth with low crowns composed of rounded tubercles, rooted and of limited growth.

Tubercles of upper cheek-teeth arranged in two primary longitudinal series (Fig. 4 **A**). CRICETINAE, or Hamsters.

Tubercles of upper cheek-teeth arranged in three primary longitudinal series (Fig. 5). MURINAE, or Rats and Mice.

The **natural distribution** of these sub-families is interesting and suggestive, for, coupled with the evidence of fossil remains, it seems to indicate that the *Muridae* originated in the Old World in early Tertiary times. The **Cricetinae** are the most ancient and on the whole the most primitive of the sub-families; they are now poorly represented in Europe and Asia, absent from Africa, though represented in Madagascar by certain very lowly forms—"living fossils"—which are doubtless the little modified descendants of the parent stock of the whole family. They are widely distributed throughout the New World, where they have developed many peculiar generic types. Neither in Madagascar nor in America has this sub-family, or its allies, had to compete with the *Murinae* until the most recent times. The **Microtinae** also appear to be fundamentally rather primitive *Muridae;* they have withstood the competition of the *Murinae* only in so far as they have been able to acquire more earth-bound habits and the power of living upon a hard diet of roots and coarse herbage; they seem to have originated in the temperate regions of Europe and Asia and to have colonized North America by way of a former land connection at the Bering Straits; unlike the *Cricetinae*, they have not succeeded in entering South America. The **Murinae** comprise many genera and are on the whole the most highly developed and certainly the most successful members of the family; they have probably originated in the warmer regions of the Old World, their range extending all through Africa and also to Australia. They reached East Africa only after the separation of Madagascar; and north-eastern Asia, in time to enter Japan, but too late to cross to America. Neither the *Cricetinae* nor the more generalized of the *Microtinae* have been able to compete with them successfully.

The living **British** *Muridae* belong to the sub-families *Microtinae* and *Murinae;* the *Cricetinae* also formerly inhabited our country, but they became extinct here towards the close of the Pleistocene period.

The **Microtinae**, or Voles and Lemmings, had many species and genera living in Pleistocene Britain. Most of these forms are now quite extinct here, although certain of them are still represented in continental Europe, or by more or less modified descendants which linger on various small islands around our coasts, as in the Orkneys and Hebrides. One of the most astonishing features in the distribution of this sub-family is the fact that, although remains of Lemmings occur in great abundance in the Pleistocene cavern deposits of Ireland, there is apparently no trace at all of either fossil or living Voles in that country.

In Great Britain itself three or four species of Vole are now living. These may be distinguished as follows :—

A. Cheek-teeth (Fig. 4 **B**) each with two well-developed roots or fangs in adults. Lower molars with their triangles peculiarly rounded, and not completely shut off from each other.

Size small (hind-foot 15·4 to 17·4 mm.*; condylo-basal length of skull 21 to 24 mm.). Tail densely haired, half as long as head and body. Ears conspicuous above the fur.

Bank Vole, *Evotomys glareolus*. (Distributed throughout the country.)

B. Cheek-teeth (Fig. 4 **C** and **D**) persistently growing and never developing roots. Triangles not rounded off, and from three to five of them are completely shut off from each other in the front lower molar. Ears not conspicuously projecting from the fur.

a. Size small ("Field Mice"). Tails about one-third the length of head and body, less densely haired than in *Evotomys*. Anterior lower molar with five closed triangles (Fig. 4 **D**).

1. Size relatively small (hind-foot 17 to 18 mm.). General colour tawny russet.

Short-Tailed Field Vole, *Microtus hirtus*. (Distributed throughout England and the Lowlands of Scotland.)

2. Size slightly larger (hind-foot 18 to 19 mm.). General colour darker and browner.

Highland Field Vole, *Microtus agrestis neglectus*. (Distributed in the Highlands of Scotland.)

b. Size large ("Water Rats"). Heavily built. Tail about half the length of the head and body, its hairs nearly con-

* 25 millimetres = 1 inch.

cealing the scaly annulations. Anterior lower molar with only three closed triangles (Fig. 4 **C**).

1. Size larger (head and body about 200 mm.; tail about 110 mm.; hind-foot usually 32 to 35 mm.). General colour brown.

Common Water Vole, *Arvicola amphibius amphibius.* (Distributed throughout England and Lowlands of Scotland.)

2. Size smaller (hind-foot 30 to 32 mm.). General colour black.

Highland Water Vole, *A. amphibius reta.* (Distributed in the Highlands of Scotland.)

In general our Voles are distinguished from our true Rats and Mice by their heavier build, blunter muzzles, smaller eyes, shorter ears, and comparatively well haired tails; the females of each species have eight mammae, two pairs on the chest, two pairs in the groin. The Bank Vole is our most primitive species; its rooted teeth have been inherited with little change from the more generalized ancestors of the sub-family; its diet is of a more omnivorous character than is that of the more highly developed voles. Our species of *Microtus* are highly specialized as feeders upon grass and coarse herbage. The Water Voles are similarly addicted to a hard diet; and they are, moreover, highly developed for their aquatic existence.

The **Murinae** are represented in Britain by four genera; these and their species may be distinguished as follows:—

A. First and second upper molars with three tubercles on the inner side when unworn (Fig. 5 **A–B**).

a. Tail not prehensile, completely haired at the tip; orifice of ear not closed by a special valve. Mammae in females six, one pair being on the chest, two pairs towards the groin.

1. Size smaller (head and body about 95 mm.; tail about 90 mm.; hind-foot about 22 mm.; ear 15 to 17 mm.).

Long-Tailed Field Mouse, *Apodemus sylvaticus.* (Distributed throughout Great Britain and Ireland.)

2. Size larger (head and body 100 to 115 mm.; tail 105 to 125 mm.; hind-foot 23 to 27 mm.; ear 17 to 19 mm.).

De Winton's Field Mouse, *A. flavicollis wintoni.* (Distributed through much of England.)

b. Tail prehensile, naked at the tip above. Orifice of ear closed by a conspicuous valve. Mammae in females eight, two pairs on the chest, two pairs in the groin. Size very small (head and body 55 to 75 mm.; tail 51 to 72 mm.; hind-foot 13 to 16 mm.; ear 8 to 10 mm.).

HARVEST MOUSE, *Micromys minutus*.

B. First and second upper molars with only two tubercles on their inner sides.

a. Upper incisors (Fig. 3 *a*) with outer side of cutting edge entire; front upper molar with five roots, its crown not so long as the combined length of the succeeding teeth, and its structure not peculiar (Fig. 5 **D** and **E**). Size large (RATS).

1. For external characters see p. 1.

Skull (Fig. 6 **D**) rather lightly and delicately built; temporal ridges not parallel, but strongly curved outwards on the sides of the braincase; the length of a parietal measured along a temporal ridge noticeably less than the greatest width between these ridges; parietal region with slight but noticeable convexity when viewed in profile; condylo-basal length 38 to 45 mm., rarely more than 43 mm.

BLACK RAT, *Rattus rattus*.

2. For external characters see p. 2.

Skull (Fig. 6 **F**) strongly built; temporal ridges nearly straight or parallel, never boldly curved outwards on the sides of the braincase; length of a parietal measured along a temporal ridge about equal to the greatest distance between these ridges; parietal region flattened, without any conspicuous convexity when viewed in profile; condylo-basal length 43 to 55 mm., rarely less than 45 mm.

COMMON RAT, *Rattus norvegicus*.

b. Upper incisor (Fig. 3 *b*) with outer side of cutting edge broken by a conspicuous notch and projection; front upper molar with three roots, its crown longer than the combined length of the two succeeding teeth, and of highly peculiar form (Fig. 5 **C**). Size small (MICE).

1. For external characters see p. 37.

Skull (Fig. 6 **E**) small and delicate; temporal ridges very faintly indicated; a strongly marked peg-like process of bone on the lower surface of the maxilla immediately below the anterior end of the infraorbital canal; the anterior palatal

foramina are very long, narrowing behind, and terminate opposite the middles of the front molars (in all other British species these foramina terminate in advance of the molars).

House Mouse, *Mus musculus*.

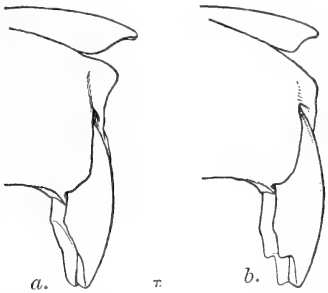


Fig. 3.—Upper Incisors of *Rattus* (*a*) *and Mus* (*b*). Much enlarged.

Of the four genera of *Murinae* dealt with above, two, *Apodemus* and *Micromys*, are indigenous to Britain; the former, at all events, was established in this country by the end of the Pliocene period. As compared with the alien genera *Rattus* and *Mus*, they appear to be less highly developed in many ways; in particular they have retained a comparatively complex dentition. The Harvest Mouse, nevertheless, is very highly specialized for its peculiar life among the corn-stalks. This specialization is visible in the diminutive size of the animal, and it is also betrayed in many of its organs, *e.g.*, in its foot-pads, which are modified for special use as "climbing irons."

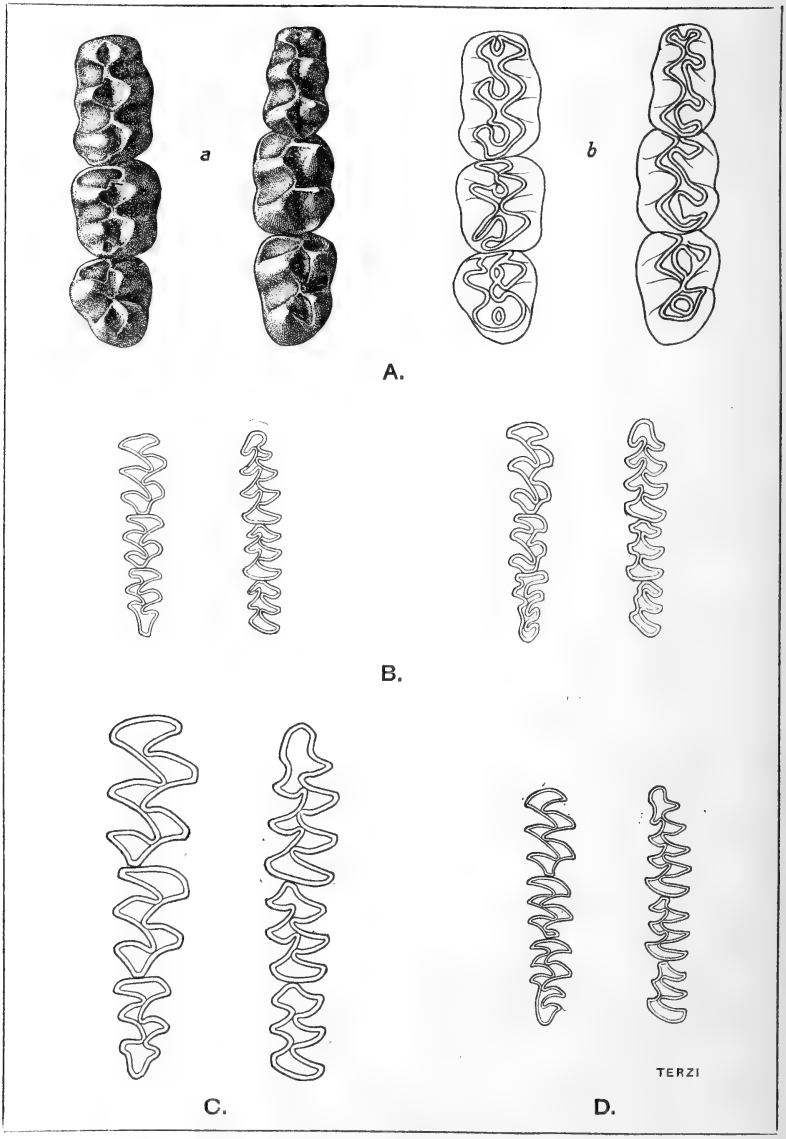


FIG. 4.—CHEEK TEETH OF *Cricetinae* and *Microtinae*.

A. HAMSTER (*Cricetus cricetus*)—*a*, unworn, *b*, slightly worn; **B.** BANK VOLE (*Evotomys glareolus*), two individuals; **C.** WATER VOLE (*Arvicola amphibius*); **D.** FIELD VOLE (*Microtus agrestis*). Enlarged (× 5). In each case, the left-hand figure represents the molars of the right upper jaw, while the right-hand figure shows those of the left lower jaw.

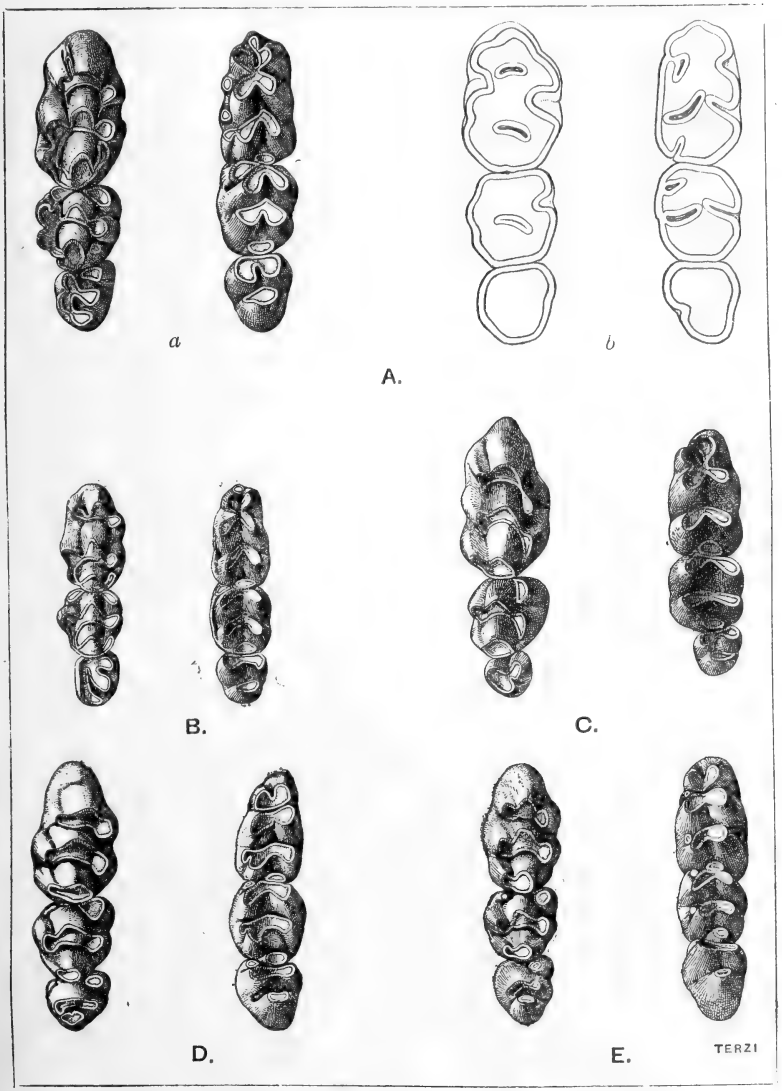
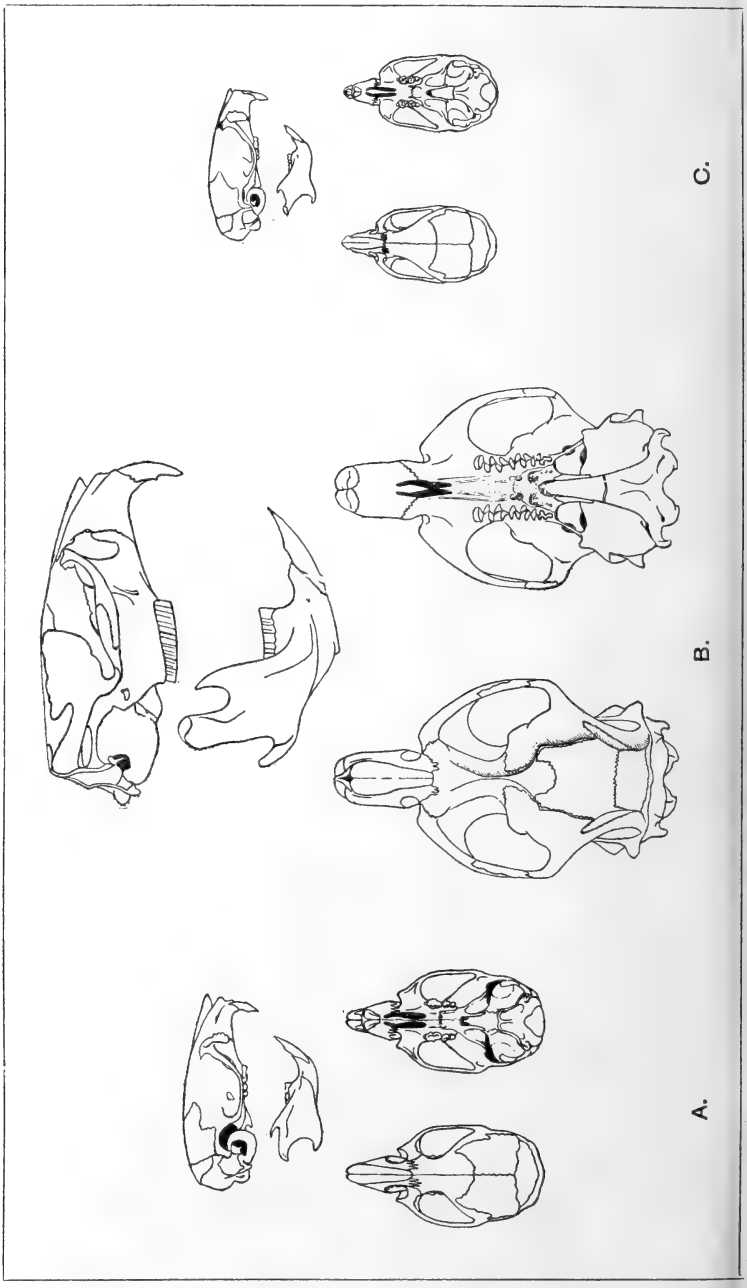


FIG. 5.—CHEEK TEETH OF *Murinae*.

A. LONG-TAILED FIELD MOUSE (*Apodemus sylvaticus*)—*a*, slightly worn, *b*, much worn; **B.** HARVEST MOUSE (*Micromys minutus*); **C.** HOUSE MOUSE (*Mus musculus*); **D.** BROWN RAT (*Rattus norvegicus*); **E.** BLACK RAT (*R. rattus*). Enlarged (figs. **A. B.** and **C.** × 10; **D.** and **E.** × 5). In each case the left-hand figure represents the molars of the right upper jaw, while the right-hand figure shows those of the left lower jaw.


A.
B.
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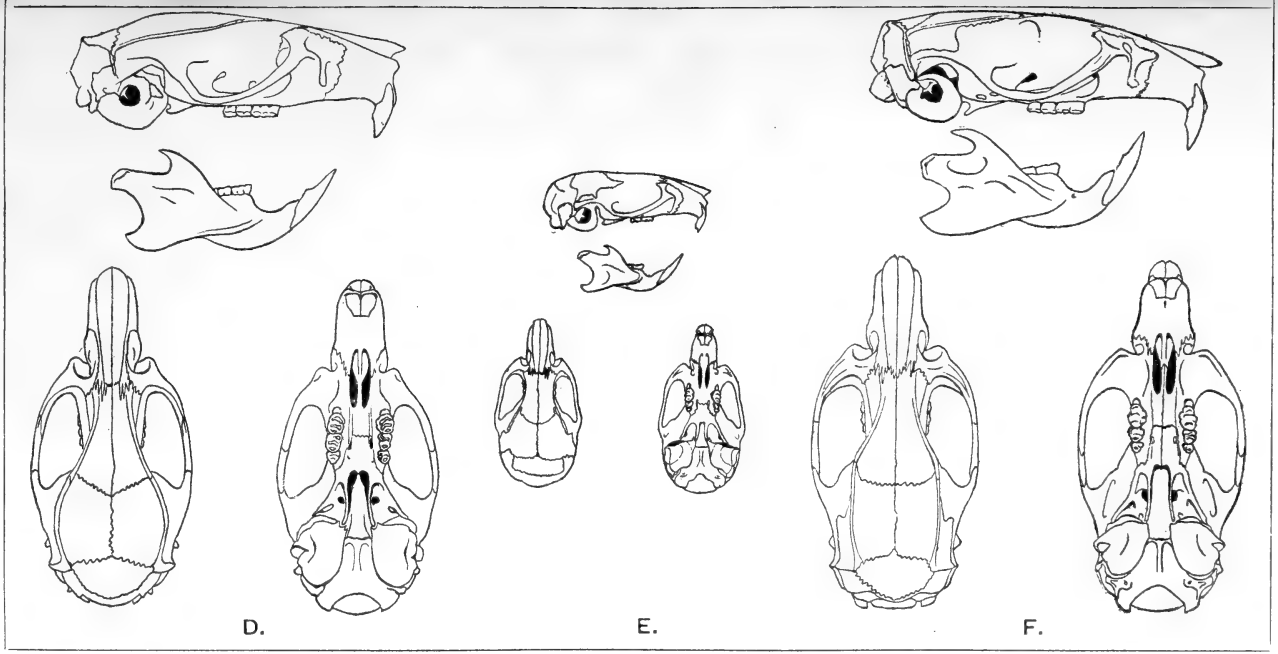

FIG. 6.—SKULLS OF *Muridae*. (Natural Size.)

A. LONG-TAILED FIELD MOUSE (*Apodemus sylvaticus*); **B.** WATER VOLE (*Arvicola amphibius*); **C.** HARVEST MOUSE (*Micromys minutus*); **D.** BLACK RAT (*Rattus rattus*); **E.** HOUSE MOUSE (*Mus musculus*); **F.** BROWN RAT (*Rattus norvegicus*). The views are:—top, profile with lower jaw; left-hand, dorsal; right-hand, ventral.

5. TABLE SHOWING RATE OF INCREASE IN RAT POPULATION POSSIBLE IN 1918.

(The calculations are based on the assumptions made on p. 24.)

The following are the numbers of *pairs* of rats possessing a chance of breeding which might be living at the dates specified, on the assumptions indicated at p. 24 :—

1918.	Generation 1.	Generation 2.					
		Litter 1.	Litter 2.	Litter 3.	Litter 4.	Litter 5.	Litter 6.
Jan. 1	10,000,000 (1)						
Feb. 1	9,208,334	10,000,000					
Mar. 1	8,416,668 (2)	9,208,334					
Apr. 1	7,625,000	8,416,668	8,416,668				
May 1	6,833,336 (3)	7,625,000	7,700,000				
June 1	6,041,670	6,833,336 (*a*)	7,050,000	6,833,336			
July 1	5,250,000 (4)	6,041,670	6,400,000	6,300,000			
Aug. 1	4,458,338	5,250,000 (*b*)	5,700,000 (*a*)	5,730,000	5,250,000		
Sept. 1	3,666,672 (5)	4,458,338	5,050,000	5,200,000	4,825,000		
Oct. 1	2,875,000	3,666,672 (*c*)	4,400,000 (*b*)	4,650,000 (*a*)	4,400,000	3,666,672	
Nov. 1	2,083,340 (6)	2,875,000	3,750,000	4,100,000	4,000,000	3,370,000	
Dec. 1	1,291,674	2,083,340 (*d*)	3,075,000 (*c*)	3,600,000 (*b*)	3,600,000 (*a*)	3,080,000	2,083,340
Dec. 31	500,000 (7)	1,291,674	2,400,000	3,050,000	3,150,000	2,800,000	1,900,000

1918.	Generation 3.						Generation 4.
	Litter 1*a*.	Litter 1*b*.	Litter 1*c*.	Litter 2*a*.	Litter 2*b*.	Litter 3*a*.	Litter 1*a*-*a*.
July 1	6,833,336						
Aug. 1	6,300,000						
Sept. 1	5,730,000	5,250,000		5,700,000			
Oct. 1	5,200,000	4,825,000	3,666,672	5,230,000	4,400,000	4,650,000	
Nov. 1	4,650,000 (*a*)	4,400,000	3,370,000	4,775,000	4,050,000	4,270,000	4,650,000
Dec. 1	4,100,000	4,000,000	3,080,000	4,350,000	3,700,000	3,900,000	4,270,000
Dec. 31	3,600,000 (*b*)	3,600,000 (*a*)		3,900,000 (*a*)			

SUMMARY of possible Rat Population on December 31st, 1918:—

	Breeding Pairs.
Survivors of Capital Stock . . .	500,000
,, Generation 2, Litter 1 . .	1,291,674
,, ,, 2, ,, 2 . .	2,400,000
,, ,, 2, ,, 3 . .	3,050,000
,, ,, 2, ,, 4 . .	3,150,000
,, ,, 2, ,, 5 . .	2,800,000
,, ,, 2, ,, 6 . .	1,900,000
,, ,, 3, ,, 1*a* . .	3,600,000
,, ,, 3, ,, 1*b* . .	3,600,000
,, ,, 3, ,, 1*c* . .	3,080,000
,, ,, 3, ,, 2*a* . .	3,900,000
,, ,, 3, ,, 2*b* . .	3,700,000
,, ,, 3, ,, 3*a* . .	3,900,000
,, ,, 4, ,, 1*a*–*a* .	4,270,000
Pairs with a chance of breeding possibly living on December 31st, 1918 . .	41,141,674

Further, we might expect in early days of January, 1919, litters in Generation 3 as follows:—

Litters 1*d*, 2*c*, 3*b*, and 4*a*; from these there might be a further 12,358,340 pairs with a chance of breeding.

Cost of maintaining breeding stock of rats (estimated at $\frac{1}{4}d.$ per day per rat):—

1918.	Number of Pairs.	Cost.
January . . .	10,000,000	£645,000
February . . .	9,208,334	537,000
March . . .	8,416,668	543,000
April	7,625,000	476,000
May	6,833,000	441,000
June	12,874,000	804,000
July	11,290,000	730,000
August . . .	15,408,000	981,000
September . . .	13,174,000	825,000
October . . .	15,591,000	1,007,000
November . . .	17,458,000	1,090,000
December . . .	17,749,000	1,145,000
Total cost . . .		£9,224,000

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